JOURNAL AND PROCEEDINGS

OF THE

ROYAL SOCIETY
OF NEW SOUTH WALES

VOLUME
110

PARTS
1-4

1977

PUBLISHED BY THE SOCIETY,
SCIENCE CENTRE, 35 CLARENCE STREET, SYDNEY

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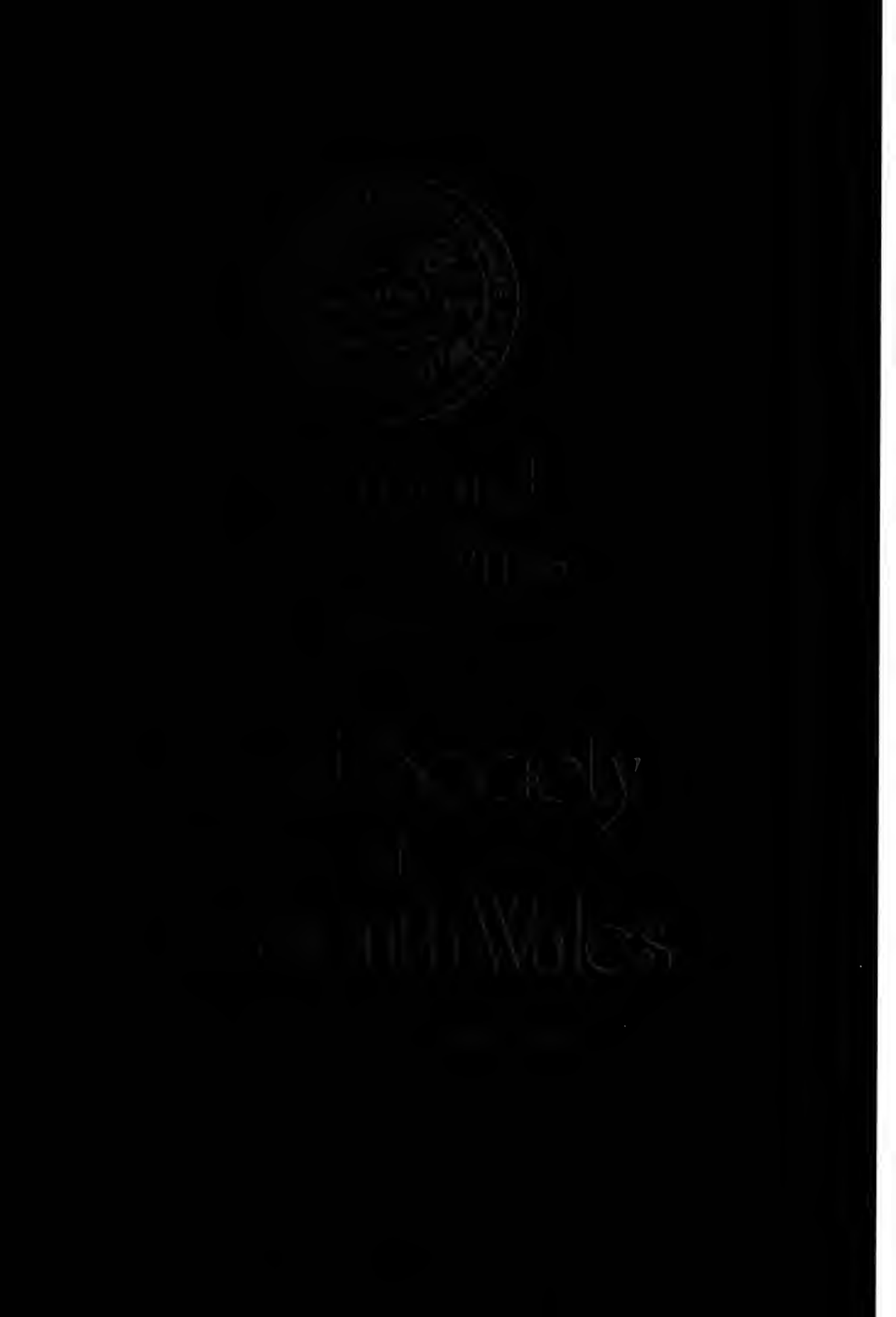
CONTENTS

Parts 1-2

Parts 3-4

Contents—*Continued*



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Journal and Proceedings, Royal Society of New South Wales, Vol. 110, pp. 1-16, 1977

Catastrophic Channel Changes in the Macdonald Valley, New South Wales, 1949–1955

H. M. Henry

ABSTRACT. Floods in the Macdonald valley, near Wiseman's Ferry, New South Wales between 1949-1955 transformed the initially narrow V-shaped channel into a very wide channel with over-steepened banks. The difficulty of quantifying as distinct from recognising change in a river channel more than twenty years after it occurred is greatly increased in the absence of large-scale maps, aerial photography and streamflow records. Buried bridges, the downstream displacement of wharves, tidal changes, the ponding of tributary creeks, old photographs and survey plans, and information obtained from farmers have been used to reconstruct the character and extent of channel change. There are signs that since 1969 the river may have begun to resume its pre-1949 form by narrowing its channel and lowering its bed.

INTRODUCTION

Between June 1949 and February 1955 the Macdonald River, a tributary of the Hawkesbury River in eastern New South Wales, trebled the width of its bed for more than 30 kilometres above its tidal zone and aggraded its bed by almost three metres, and in doing so it completely changed the shape of its channel. During the preceding 80 years there had been a marked fall in the number of people living in the Macdonald valley; no extension of settlement had taken place, there had been no relevant change of land use, nor any interference by man with the river's natural flow.

The Macdonald River is 180 km long, and has a drainage basin a little more than 2000 km^2 in area. Its banks, from six to nine metres high in the study tract between Marlo Creek and Wright's Creek (Fig. 1) have only been completely submerged by floodwaters on four occasions since 1867. Although average rainfall in the valley is about 750 mm, prolonged periods of low flow are common and periods of no flow occur.

For fifteen years after the flood damage there was no apparent change in the channel of the Macdonald River. Since 1969, however, there are signs that the river may be returning to its pre-1949 form by regrassing its channel, stabilising, extending and building up its low benches, and by degrading its bed.

According to Stevens et al (1975),"... the effect of a particular flood event on river form is indicated by the ratio of that flood's peak discharge to the average annual peak-flood discharge". The history of the Macdonald since 1867 suggests this is an over-simplification. Lesser floods on the Macdonald between 1949-1955 were more destructive than the major floods which preceded them: clearly the whole meteorological and hydrological context must be taken into consideration. Nevertheless, the Macdonald River exemplifies what Stevens et al (1975) call "non-equilibrium river form". Hickin and Page (1971) have pointed out that the narrow sandstone valleys of central eastern New South Wales are particularly subject to devastation by major floods.

The present study results from frequent visits made to the Macdonald valley since 1952. Fieldwork on channel changes was started in 1969 and levelling completed in 1974.

THE SETTING

The Macdonald River rises on the divide between the Hawkesbury and Hunter River systems at an altitude of about 650 m (Fig. 1A). In its downstream tract the river is deeply incised into a dissected sandstone plateau 200-300 m high, while for nearly 50 km above its junction with the Hawkesbury it is flanked by a narrow and discontinuous floodplain. In few places is the steep-sided valley more than 400 m wide.

The catchment area of the Macdonald lies entirely within sedimentary Triassic rocks of the Sydney Basin. The river is incised throughout its length through the overlying Hawkesbury Sandstone into the upper formations of the Narrabeen Group of sandstones, claystones and shales, with sandstone strongly predominating in the Macdonald valley (Galloway, 1967). At least two-thirds of the surface rock is Hawkesbury Sandstone, a fact reflected in the surface channel deposits which consist of well-sorted sub-angular to sub-rounded, medium to coarse sand. According to Probert (1971) recent sand deposits in the channel of the Macdonald River are almost gravel-free, with the silt fraction rarely exceeding five per cent.

The Macdonald River is tidal for 13 km above its junction with the Hawkesbury, and for 40 km above the tidal limit its gradient does not exceed 40 cm per km. The valley fill is up to 50m deep for 25 km from Wiseman's Ferry. Results from seismic and resistivity probe surveys have been inconsistent (Probert, 1971) but data obtained by a geophysical group from Macquarie University suggest that the fill is 45 m deep 3 km above St. Albans.

Owing to the rugged topography and barren sandy soils more than 95 per cent of the Macdonald drainage basin is uncleared. Although rainfall in the valley is fairly well distributed throughout

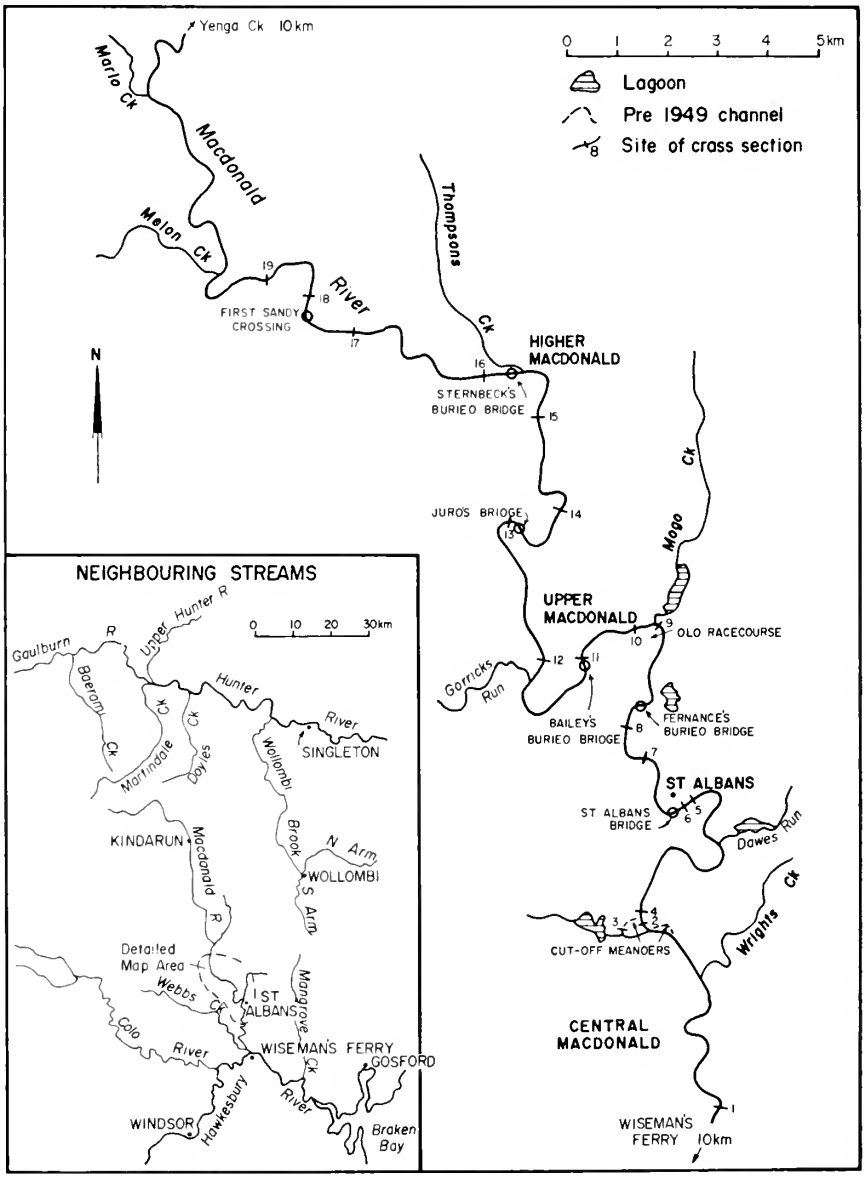

Figure 1. A. Location map of the study area

B. Map of the main settled tract of the Macdonald River above tidal influence as discussed in this report.

the year, only floodplains and two small upland areas of less than 15 km^2 are not still covered by the original dry schlerophyll forest.

Like many coastal streams in New South Wales the Macdonald River appears to be incised within its floodplain. The banktops are inundated only by rare high floods. In discussing the streams of the Cumberland Basin west of Sydney, Pickup (1974) suggests as an alternative to incision that their channel capacities are related to events less frequent than one-to-two year floods, the most common he believes being floods with return periods of from four to seven years. However, if the Macdonald River is not incised it seems clear that, in its present form, its channel must be related to flows of more than twenty years recurrence interval, or have been formed during a period of considerably higher discharge than the present.

BEFORE THE 1949-1955 FLOODS

From the early 1820's when the first white settlers moved into the Macdonald valley, it had experienced a succession of major floods at intervals of more than 20 years - specifically, in 1867, 1889, 1913 and 1949. Such floods do not appear to have produced noteworthy geomorphic changes - not even the 1949 flood which, with the possible exception of the 1889 flood, was the highest on record. However, the 1949 flood was but the first of a series of floods which occurred during the next six years, and although not as high as the floods of 1867, 1889, 1913 and 1949, those lesser floods effected a spectacular change in the river channel. The enlargement of the Macdonald River's channel, and its change from V-shaped to rectangular cross-sectional form between 1949-1955, are illustrated in the paired photographs (Plates 1 to 6).

The river flats in the Macdonald valley had been surveyed before 1835 and the best land was soon granted by the Crown. Since arable land was so limited and there were five or more children on every farm in those days, farmers cultivated their floodplains to the banktops and down the riverward sides. How this could be done successfully for years at a time is suggested by the cross-sections of Figure 2 and the data of Table 1. Sloping banks above the river also provided the best pasture in dry times. The banks were important: farmers who could not possibly have foreseen the devastation to be caused by the 1949-1955 floods, used to take shovels when part of a bank was washed away and reshape it so that it would offer as little resistance as possible to further floods, and would then encourage the grass to grow over it.

The practice before 1949 of using tree-trunks as footbridges suggests the narrowness of the river above St. Albans. In 1940 C.J. Bailey whose farm is 2 km above St. Albans placed a 9 m pole across the river, and until 1949 he was able to cross dry-footed even when the river rose by a metre. When it rises a metre at this point today the river is more than 50 metres wide (see item 8, Table 2). W. Bailey recalls when a pole would span the Macdonald almost anywhere above Mogo Creek. G. Sternbeck remembers the river as a creek running through reeds when he was a boy. It was then less than 8 m wide at points where it is more than 40 m from bank to bank today (Plates 7 and 8).

Older farmers tell how until the early years of the century reeds 3 m high grew thickly along the banks from Higher Macdonald to Wright's Creek. These were usually *Phragmites australis* and the introduced *Arundo donax* and they were equally abundant in tidal and non-tidal zones. No doubt they reflected the sluggish flow of the river, and growing so densely their deeply-rooting rhizomes must have helped to protect the banks from erosion. The disappearance of the reeds was not due to the floods: when fencing wire became readily available many farmers took up dairying and the cattle very nearly wiped them out. There had been little fencing in the Macdonald before 1900; most farmers had only one or two head of cattle, and farm animals were tethered overnight. However in view of the lack of damage to river banks in the 1949 flood it seems unlikely that destruction of reeds was an important factor in subsequent erosion.

MACDONALD RIVER FLOODS 1949-1955

The history of the floods on the Macdonald River between 1949-1955 is as follows:

1. The June 1949 flood, nearly 12 m high at St. Albans, was the first major flood after 1913. With the 1889 flood it was the highest on record. It did little damage to the banks but it deposited a metre of sand in the river bed from Marlo Creek to Wright's Creek.

2. This unprecedented sanding-up continued during 1950, the wettest year in east-central New South Wales since continuous rainfall records began in 1858. The annual discharges of both the Hawkesbury and Hunter Rivers for 1950 are the highest on record. No bank-submerging flood occurred on the Macdonald in 1950 but, according to multiple regression analysis carried out by the hydrology section of the N.S.W. Public Works Department (N.S.W. Department of Public Works, 1975), the estimated annual discharge at St. Albans in 1950 was more than double that of any year since 1913, which it exceeded by more than 90 per cent. The estimated monthly discharge at St. Albans in June 1950 was more than double that of any other month between 1903 and 1973.

3. The August 1952 flood was 2 m lower than the 1949 flood at Higher Macdonald but was responsible for the first general destruction of banks along the Macdonald. Twice in one week floodwaters covered flats which had been completely submerged only three times since 1867. The flood raised the height of the bed by another metre.

4. There were more floods during 1953-54. They were lesser floods, but on the

Hunter (and, according to unpublished comparative flood analysis by the writer, Hunter River floods correlate more closely with Macdonald River floods in respect both of incidence and stage than do those of the Hawkesbury) the 1953-1954 floods were higher than any had been for nearly twenty years before 1949.

5. The last of the major floods occurred in February 1955. This was the highest flood ever recorded on the Hunter. On the Macdonald it only reached 6.65 m at St. Albans, and for the most part it did not break the banks, but in many places above Mogo Creek it was the most destructive of the floods, and it completed the demolition of benches between Marlo Creek and Wright's Creek.

BANK EROSION AFTER 1949

The widening of the channel by the 1949-1955 floods and its changed cross-sectional form can be seen by comparing the paired Plates 1 to 6. Without comparative aerial photography it would not be possible to show that the sites illustrated are typical of channel change from Marlo Creek to Wright's Creek during the flood period. Systematic aerial photography of the Macdonald valley dates only from 1954, and most earlier R.A.A.F. photography has been lost or destroyed. However, the National Library in Canberra holds R.A.A.F. photographs of the Mellong area taken in 1941 which cover the Macdonald valley north from Upper Macdonald. Although they begin 10 km above St. Albans they do show that the Macdonald channel in 1941 was very narrow relative to its present form (Plates 7 and 8).

Survey regulations published by the N.S.W. Department of Lands have always required surveyors to set out both sides of a watercourse on their plans, but old surveys are of disappointingly little assistance in determining the width of the Macdonald River before 1949. On comparing old surveys with old photographs it is clear that surveyors adopted the tops of the river's high shelving banks as its boundaries although on the average they were over-topped less than once every twenty years. As a result the river is shown on old surveys as being far wider than it was except at time of high flood; and difficulties are compounded because channel widening between 1949-1955 so often consisted in the river stripping back banks which had sloped at less than 15° leaving over-steepened banks in approximately former banktop position.

There are some places, however, where some measure of channel widening can be obtained from surveys made before 1949. In 1892 the surveyor Charles Robert Scrivener, who later became the first Commonwealth Surveyor and laid out the city of Canberra, spent ten weeks on the Macdonald River as a Department of Lands surveyor pegging out a new parish road between St. Albans and Melon Creek. At Higher Macdonald Scrivener surveyed an access road to Preston's Gully a kilometre downstream, endorsing his plan as follows: "About half the land taken for the road is good cultivable soil; the other is sandy and of little value being practically part of old bed of river raised some feet above present level of river. The road is practicable". Scrivener's access road was used for 50 years, but it disappeared in the 1949-1955 floods, for it ran along the middle of the widened river bed shown on Plate 6.

Last century a racecourse was laid down inside the bend of the Macdonald River below Mogo Creek junction; it is shown in Scrivener's field notebooks of 1892. The course was registered with the Australian Jockey Club and races held there until the 1920's. A survey plan prepared in 1921 plots banktop positions in unusual detail. Comparison with a 1965 aerial photograph enlarged to the same scale shows that not only the banks but many acres of floodplain were demolished by the floods.

A subdivision plan of land at Upper Macdonald prepared in 1947 when E. Jurd acquired two acres to build a new dairy shows how the 1955 flood cut swathes 30 m wide from banks which had survived the higher floods of 1949 and 1952. Jurd's land extended 43 m from the river and was ploughable to its boundaries. After the 1955 flood Jurd's dairy stood at the edge of a nine-metre drop to the channel; his cultivation paddock with its 165 metre frontage to the road had disappeared, at one point taking the road with it. For 400 metres further downstream the river had also stripped away the bank.

When farmers began dairying they erected fences across the river bed consisting of posts driven into the sand two to four metres apart connected by fencing wire. These provide another measure of the widened channel. W. Bailey of Higher Macdonald had five fence posts in the river before 1949 but by 1960 their number had increased to twenty. Many other farmers, particularly above St. Albans, found it necessary to increase three- and four-fold the number of their fence posts between 1949-1955.

At only one place between Marlo Creek and Wright's Creek did significant widening of the old channel not occur. Five kilometres below St. Albans two consecutive meanders were cut-off by the 1952 flood, and 23 years later the upper cut-off meander still preserves some of the dimensions of the former stream (Plate 3, and Fig. 2, Section 3).

CHANNEL AGGRADATION 1949-1955

The evidence that the bed of the Macdonald River aggraded by about 3 m between 1949-1955 is conclusive.

1. Buried Bridges

Four bridges crossed the Macdonald between St. Albans and Higher Macdonald before 1949 (see Fig. 1B). Although they stood up to 3 m above the bed all were buried in sand between 1949 and 1955.

Fernance's bridge, three kilometres above St. Albans, stood 3 m high and many farmers rode their horses under it. The 1949 flood raised the bed by a metre here, and the 1952 flood raised it by another metre. After the 1952 flood subsided C.J. Bailey found the river bed a metre higher than the week before. His account of catastrophic sanding-up

by the 1952 flood is supported by other farmers. Aggradation went on and after the 1955 flood Fernance's bridge was buried to its decking in sand. The Upper Macdonald road continued to use it until 1958, but it was now no more than a ford, and even at low stage the river flowed over it.

Bailey's bridge, two kilometres upstream from Fernance's bridge, stood 3 m above the bed before 1949. According to a local farmer the 1949 flood aggraded the bed by a metre at this point, and sanding continued until by 1955 only the tops of the bridge piles were above the sand.

Jurd's bridge, seven kilometres above Bailey's bridge at Upper Macdonald, is presently spliced to the top of a nearly buried bridge which was once almost 3 m above the river. E. Jurd estimates that the bed aggraded by more than 2.5 m between 1949 and 1955.

Sternbeck's bridge at Higher Macdonald (Plate 5) was also buried by sand between 1949 and 1955. The late Keith Sternbeck, the writer's field assistant for a year, used to ride a draught horse under the bridge in the 1930's when returning to his uncle's farmhouse after ploughing. The 1949 flood raised the bed by nearly a metre and in 1953 a new bridge was built 100 m upstream. By 1956 the old bridge was buried and its decking was not re-exposed until June 1973 when the removal of debris from above the new bridge led to its re-excavation. Several months later it was again covered by a few centimetres of sand although the river was running over it.

2. High - Level Bridge at St. Albans

The high-level bridge at St. Albans demonstrates the aggradation of the river less spectacularly. Plate 1, taken about 1910, shows the steel piles braced by three sets of crossed girders; in the 1973 photograph (Plate 2) only two-and-a-half sets are still above the sand. The distance between the horizontal girders is more than five metres. According to local residents nearly all the sand was deposited during 1949-1955.

3. Aggradation of the River Bed above Higher Macdonald

No bridge was ever built above Higher Macdonald and the old road forded the river eight times between Sternbeck's bridge and Marlo Creek. Fifty years ago there were seven farms above the first sandy crossing, but by 1949 they had been abandoned. W. Bailey used to run cattle from Melon Creek to above Yengo Creek, and in dry times he would dig a soak in the river bed near the foot of a 3 m-high rock outcrop to water his cattle. According to Bailey those rocks were buried during 1949-1955. He considers that aggradation of the Macdonald River near Yengo Creek junction, as well as of tributary creeks in the area, was not less than at St. Albans and Higher Macdonald.

Two hundred metres above sea-level, Kindarun is a cattle property on the upper reaches of the Macdonald River for which there are continuous rainfall records from 1914 onward. On the night of June 18 1949, 425 mm of rain fell at Kindarun - the gauge overflowed at 325 mm but 425 mm of water were measured in an oil drum on a neighbouring property next morning. River flats were destroyed in the resulting flood, the channel width was doubled in many places and large trees were torn out of the ground. According to Mr. A. Halton of Kindarun, little sand was deposited because the river was running too fast. However, by 1955 the bed had aggraded by two metres at Kindarun; it does not seem to have aggraded or degraded since.

4. Ponding of Tributaries

Some of the tributaries of the lower Macdonald apparently did not aggrade at the same rate as the river and consequently formed lagoons near their mouths. Mogo Creek joins the Macdonald River 4 km above St. Albans and for about 10 km before reaching the river it flows along a flat-floored valley about 150 m wide. This is the St. Albans Common established in 1825. Farmers who hauled logs across the Common by horse team before 1949 say that during droughts there was not enough water at the lower end of the Common to water a horse. Since 1949, there has been a lagoon at the lower end of Mogo Creek more than 1 km long and 100 m wide; even in dry times when the river has stopped running the lagoon has not greatly diminished. When the river rises without a corresponding rise in Mogo Creek it backs up into the lagoon and floods the Wollombi road, which once formed part of the Great North Road.

Other permanent lagoons formed near St. Albans between 1949 and 1955 are:

1. Dawes Run, a minor tributary of the Macdonald 2 km below St. Albans, flooded 40 ha of grazing land near its junction with the river during the 1949 flood; they are still under water.

2. A large lagoon east of the river above Fernance's bridge used to dry out in very dry periods - it was dry in 1946. It filled in 1949 and has not been dry since; a rail-fence dividing two properties is still under water.

3. A large depression behind the west bank of the river, 2 km above the cut-off meanders at Central Macdonald, once often dry, has held a lagoon since 1949.

Tributaries of the Macdonald River above Mogo Creek did not form ponded lagoons as a result of the floods but the lower reaches of some became heavily silted. Thompson Creek traverses a flat near C. Sternbeck's farm-house at Higher Macdonald and Scrivener called it a "marshy flat" in his field notebook. For 40 years Sternbeck made only minor repairs to the fences subdividing the flat, but after the 1949 flood he found it necessary to raise them by half a metre because they were being buried. During the next five years Sternbeck raised them again twice, two metres in all. The fences have not needed attention since 1956 because, according to Sternbeck, the flat has not continued to aggrade.

5. Wharves and Tides

Although the Great North Road ran through St. Albans from 1885 to 1929, farm produce was transported out of the valley by small river-boats. Corn was carted from Higher Macdonald to a landing near Fernance's bridge in the mid-19th century, but the top wharf on the Macdonald stood at St. Albans for nearly 50 years, and Wharf Street appears on all old plans. The wharf was moved 3 km downstream about 1870 and remained there until 1917 when continued sanding forced its further removal to Stoney Gully on the now cut-off meander. It is significant that each time the wharf was displaced downstream it was 3-4 years after a major flood.

In 1892 an 18-foot sailing boat with sweeps arrived at St. Albans and its crew were told that a vessel of that size had not reached the village for more than twenty years ("Hawkesbury Herald", November, 1905). The crew was also told that the recent 1889 flood had been 1.5 m higher at St. Albans than the 1867 flood and considerably more destructive.

Until 1949 the Macdonald River was tidal to St. Albans. The parish map showed the limit of tidal influence to be 300 m downstream but local residents say that very high tides flowed nearly 400 m beyond the high-level bridge. After the 1949 flood the Macdonald was tidal only to Wright's Creek, and this has been so until recently, when some spring tides have reached the nick-point at the lower cut-off meander (see later).

EXPLANATIONS OF CHANNEL CHANGE

That sanding-up had been continuing for nearly a century before 1949 can be easily understood, but the changes in the Macdonald River's channel between 1949 and 1955 were not foreseeable since no significant change in land use or extension of settlement had occurred. According to local farmers, there was as much cleared land on the Macdonald in 1889 as in 1949, and the population was greater. In 1865 Canon Greaves wrote that 800 people lived on the Macdonald (Elkin, 1955). By 1933 the population of the St. Albans police patrol district, which included the whole of the Macdonald valley, had fallen to 575; and between 1932 and 1949 the number of electors enrolled in the Macdonald valley fell from 190 to 97 (Wiseman's Ferry subdivision, Hawkesbury State electorate).

In 1966 at the request of an inter-departmental committee on flood mitigation in the Nepean-Hawkesbury valley, the N.S.W. Soil Conservation Service investigated the origin of recent sand deposits on the Macdonald and Colo Rivers. It reported (Dyson, 1966) that the deposits had resulted from erosion of the steep sandy slopes bordering the valley and that bushfires had been the main factor contributing to such erosion, other important factors including burning-off to provide winter pasture and felling and transport of timber. Dyson (1966) thought that erosion due to farming was small compared with the extensive erosion and sanding which had occurred throughout the timbered area, but apparently did not realise that the sanding-up had taken place within a period of six years, for he did not mention the 1949-1955 floods. He also overlooked the channel widening and thereby missed one of the most important sources of the sediment. As Leopold (1956) pointed out: "Bank-cutting is usually a process of sediment-trading, erosion in one place and deposition in another". Figure 2 compares reconstructed cross-sections of the former channel with cross-sections taken at the same places today and suggests that much of the sand deposited could well have come from demolished banks upstream.

There is no doubt that bushfires, burning-off and timber-getting contributed to aggradation of the Macdonald River, but catastrophic sanding-up only occurred between 1949-1955. Farming and related activities were not the primary causes of changes in the channel; these resulted from the cumulative effect of repeated high floods, probably accentuated by a raised floodplain water-table resulting from channel aggradation and the unpredented rainfall of 1950. One farmer at Upper Macdonald has said that he found bank erosion worst in places where he had previously noticed "springs" in the banks.

Morris (1956), a local resident, described the floods of 1867, 1889 and 1913. He wrote of the floods of 1949-1952 (sic) as follows: "In 1949... the river banks were fringed in places with water gums which were there when Captain Cook landed, and they had withstood the three major floods mentioned as well as intermediate smaller ones by the dozen. But with the series of floods which started in 1949 the banks began to give way and a moderate-sized flood in 1952 took the lot - roots and branches as well as the banks on which they grew, and where the river skirted the mountainside it cut right back to the mountain rocks or hard formation. With the displacement of so much soil throughout the entire length of the cultivated Macdonald valley it followed naturally that the river bed would collect it. It did, and the bed is yards higher today than it was after the flood of 1889". Morris also referred to the permanent lagoons caused by the floods: "The result of this silting of the river bed is that acres of rich low-lying farmlands are now permanent lakes".

Hack and Goodlett (1960) described a rainstorm on the Little River, Virginia, so violent that in some places it tore up the entire floodplain and washed away its cover of trees. By a remarkable coincidence it occurred on the same day as the 1949 Macdonald River flood, 18 June 1949. Hack and Goodlett considered that although floods like the Little River flood may have a recurrence interval of 600 years "they occur frequently enough to exceed in importance as erosive agents all intervening floods that do not damage the forest". The floods of 1949-1955 on the Macdonald River illustrate that possibility. The river's uncleared reaches and densely forested tributary gullies by no means went unscathed by the floods. A. Bailey describes large trees lying in all directions along the creeks after the 1952 and later floods; and at the creek heads the natural gibber swamps to which he used to take cattle in dry times had disappeared leaving only boulders and white sand. Other farmers describe tall trees falling as their root systems were undermined by successive floods, and

say that in many narrow valleys (e.g. Dawes' Run and Gorrick's Run) creek beds had doubled in width after the 1952 flood.

FLOODS ON NEIGHBOURING STREAMS 1949-1955

Major flooding occurred on all rivers in east-central New South Wales between 1949 and 1955. On neighbouring Webb's Creek and Mangrove Creek (Fig. 1A) the effects of the floods were comparable to those on the Macdonald River. Twenty kilometres up Webb's Creek from Wiseman's Ferry the creek bed aggraded by more than 2 m between 1949-1955 and banks were eroded although less uniformly than on the Macdonald. On Mangrove Creek the 1949 flood was more destructive than later floods and destroyed creek-flats back to the watershed. On June 17 and 18, 1949 Mangrove Mountain at the head of Mangrove Creek had 159 and 197 mm of rain respectively. During each flood on Mangrove Creek large quantities of sand were deposited until by 1955 the creek bed at Upper Mangrove had aggraded by 3 m. It has not aggraded since.

Wollombi Brook has a drainage basin nearly equal in area to the Macdonald, and a mean annual discharge 50 percent greater. There was the same destruction of banks along the lower Wollombi as on the Macdonald, but above Wollombi the banks of the South Arm were not seriously eroded, and on the North Arm they were not eroded above Cedar Creek (Page, 1973). Deposition of sand was extremely heavy but appears to have been less heavy than on the Macdonald: at no point did the bed aggrade by more than 2 m during the flood period. Overbank deposition was particularly heavy on the South Arm which has a shallow channel.

The Colo valley was less affected than the Macdonald by the 1949-1955 floods. Although the 1949 flood reached the record height of 20 m at Upper Colo, 30 km from the Hawkesbury, it did little damage to the banks, and the channel was not ravaged by ensuing floods to the same extent as the Macdonald. There was heavy deposition of sand in the tidal zone, but the bed seems to have aggraded only by about a metre above Central Colo, and according to local farmers the bridge at Upper Colo stands nearly as high above the bed as when built 40 years ago.

Doyle's, Martindale and Baerami Creeks are tributaries of the Hunter or Goulburn Rivers but have a common watershed with the Macdonald or rise near its upper reaches. Their valleys widen where they reach the Coal Measures of the Hunter valley, and by comparison with the other streams mentioned their banks have a high silt and clay content. All three suffered severe bank erosion between 1949 and 1955, but deposition of sand was patchy and nowhere seems to have exceeded 60 cm. Ellis (1971), describing the effects of the floods on Baerami Creek, does not mention deposition of sand.

EVIDENCE OF SUBSEQUENT READJUSTMENT OF CHANNEL FORM

The channel of the Macdonald River changed little between 1955 and 1970. In 1970 the benches at the foot of the over-steepened banks were still narrow, hummocky and largely ungrassed. Aerial photographs show that there were only minor changes in their size and disposition between 1955 and 1970. The river bed remained wide and flat. Similarly, Page (1973) considered that the most distinctive form-element of the comparable Wollombi Brook was its almost flat bed.

Since 1970 there have been the following signs of change:

1. Narrowing Bed

In many reaches since 1970 the river has widened the low benches, now levelled and grassed, and in doing so has established a stable course within its overwidened bed. Schumm and Lichty (1963) attributed the reconstruction of the Cimarron floodplain in U.S.A. to, interalia, unvegetated sand-bars becoming attached to banks in places where channels had been abandoned. On the Macdonald, a much narrower river, such a development only seems to be lasting when accompanied by a strong growth of grass.

It is by no means clear why the Macdonald River began to narrow its channel again only after 1970. Since it was not due to changed land use or interference with the natural flow of the river, the explanation must presumably be sought in the frequency and distribution of high and low flows. Local farmers account for the widening benches in terms of streamflow: a big flood, they say, demolishes sand-bars and either carries the sand away or spreads it over the bed, whereas a small flood merely lifts it and deposits it on the benches. The data in Tables 1 and 3, however, do not suggest any obvious meteorological or hydrological reason for the changes which have only become apparent since 1970.

The explanation may be partly biological. The writer was told by a farmer on Martindale Creek, a tributary of the Hunter River having a common divide with the Macdonald (Fig. 1A) that after a minor flood some years ago the channel floor was covered for miles with eucalyptus seedlings which grew several inches before they shrivelled and died. The rapid colonisation of parts of the Macdonald River channel by grass after 1969 may be analogous. In February 1969 a flood, about 3 m high at St. Albans, deposited large quantities of decomposing leaf-mould and other organic detritus in the bed of the lower Macdonald. In mid-1969 a group from Macquarie University found gas pits nearly one metre in diameter in the Fernance's bridge area; the writer found other smaller pits near Bailey's buried bridge. Methane gas was being emitted from the pits which were found to overlie deposits of organic matter up to a metre deep covered by channel sand. It may be possible that the deposition of exceptional quantities of organic material in the Macdonald's bed in 1969 facilitated the growth of grass during the next four or five years.

2. Degrading Bed

In September 1954 the N.S.W. Water Conservation and Irrigation Commission installed a staff gauge at St. Albans and, based on rating tables which have been recalculated at least yearly, cease-to-flow height in 1967 was about the same as in 1954,

although fluctuations over a range of about 25 cm had occurred. Cease-to-flow height has tended to fall slowly since 1967 but at the St. Albans gauge it appears to be still within 30 cm of its 1954 height. It is presumably not coincidence, however, that pools a metre deep have recently developed in reaches of the river between St. Albans and Central Macdonald which were ankle-deep before 1970, and that floods, including the 6 m flood of June 1974, have not filled them but have deepened and extended them. Other evidence that the river may be lowering its bed is provided by high tides which today flow 1 km further upstream than they did in 1970, and the fact that a reach of the river 1 km below Wright's Creek, across which it was possible to wade at low tide two years ago, is now permanently more than a metre deep.

There is one factor which will continue to delay the degrading of the Macdonald's bed, at least near present tidal limits. In adopting a shortened course across the neck of the lower cut-off meander at Central Macdonald in 1952, the river became superimposed on a bed of indurated ferruginous sand, the existence of which had not been known to local farmers. After 24 years the river is still incised less than 0.5 m into this bed the upper surface of which is 2 m above the former level of the river. The indurated bed is about 2 m thick, and overlies a deposit of clay with a high organic content, below which there is unconsolidated sand (M.F. Clarke, pers. comm.). Such a nickpoint has impeded the discharge of sand by the river, and probably helped to delay the draining of lagoons below St. Albans; however, pools a metre deep have now developed in the river bed less than 2 km upstream.

3. Future Reduction of Bank Slopes?

In discussing the stability of the banks of the George's River near Sydney, Foster and Nelson (1971) considered them to be unstable when their slope exceeded 26 degrees. The Macdonald's banks are generally sandier than those of the George's River (Probert, 1971; Warner and Pickup, 1973), and at eight of the nineteen cross-section sites in Table 3 the slope of the tallest bank segment exceeds 30 degrees. Data in Table 3 suggest that the slope of the tallest segment of unaltered banks usually does not exceed fifteen degrees. It seems likely therefore that many of the flood-steepened banks of the Macdonald will eventually suffer a marked reduction in slope, and this too will contribute to restoring the shape of the former channel.

CONCLUSION

Amongst well-known papers describing rapid changes in river channels are reports by Smith (1940), Dobbie and Wolf (1953), Hack and Goodlett (1960), Schumm and Lichty (1963), Stewart and Lamarche (1968) and Burkham (1972). The papers fall into two groups. Dobbie and Wolf (Lynmouth, Devonshire flood of August 1952) Hack and Goodlett (Little River, Virginia, flood of June 1949), and Stewart and Lamarche (Coffee Creek, California, flood of December 1964) describe single events of catastrophic intensity, while Smith (rivers of western Kansas), Schumm and Lichty (Cimarron River, Kansas) and Burkham (Gila River, Arizona) describe river metamorphosis caused by climatic fluctuations in subhumid and semiarid regions. The authors of the second group acknowledge the important role of exceptionally high floods in introducing a period of change. In his study of Wollombi Brook, Page (1973) considered that the 1949 flood, which he discusses as a catastrophic event, represented an "initial exceedance of a resistance threshold, after which erosion was continued by less spectacular flows". This would be an oversimplification if applied to the Macdonald River, where the period June 1949 to August 1952 inclusive (two major floods) was the principal sanding-up period, while the overlapping period August 1952 to February 1955 inclusive (also two major floods) witnessed the demolition of river-banks. If there were a catastrophic event on the Macdonald River, it was the August 1952 flood, as Morris (1956) indicates. On the morning after the August 1952 flood a Sydney newspaper reported: "The Macdonald River is now nearly 300 feet (90 metres) wide and a swathe has been cut through most of the farms between Higher Macdonald and St. Albans". (Sydney Daily Telegraph, 19th August, 1952).

Burkham (1972) believed that the widening of the channel of the Gila River, Arizona, involving extensive destruction of the floodplain between 1905-1917, and its reconstruction between 1918-1964, was a repetitive process occurring naturally; he seemed to envisage a cycle recurring at intervals of one or more centuries triggered off by catastrophic floods. There is no way of knowing whether the 1949-1955 Macdonald River floods represent the destructive phase of such a cycle, but there is some evidence in the aerial photographs of 1941 that the former V-shaped channel was a recovery phase since the outlines of the present banks can be identified at many points. Furthermore the 1955 flood brought evidence to light at Higher Macdonald of a time when the channel may have been as wide as it is today: after the banks collapsed four tree-trunks were revealed in situ side by side, deep within and five metres below the surface of the high bank. Today they occupy a low bench a metre above the river bed.

POSTSCRIPT

As one of a number of projects to provide water for the Gosford-Wyong region before the end of the century, the N.S.W. Department of Public Works is considering building a 10-metre-high weir near Fernance's hridge (Department of Public Works, 1975). What proposed engineering ingenuities can justify a plan to build a 10-metre-high weir on a sandbed stream of intermittent flow which aggraded its bed by three metres within six years at the weir site and for 30 km upstream although no artificial structure impeded the river's flow? Perhaps after further consideration the plan will not be proceeded with. However, the proposal may result in serious hydrological and geomorphological work being carried out on the Macdonald River for the first time. Whether undertaken by a government department or private research, it will he regrettable if further changes in the channel of this interesting sandhed stream, so accessible from Sydney, are not adequately monitored.

TABLE 1

NUMBER OF DAYS BETWEEN OCTOBER 1954 AND DECEMBER 1973 ON WHICH MACDONALD RIVER EXCEEDED 1 METRE, 1.5 METRE AND 3 METRE LEVELS AT ST. ALBANS #

Exceeded	1 m	1.5 m	3 m
Oct. 1954 to Feb. 1955	18	10	4
1958	19	9	1
1959	11	3	0
Jan. to June 1960	2	0	0
Oct. 1961 to Apr. 1962	50	22	1
Aug. 1962 to Dec. 1962	6	4	2
1963	43	25	5
1964	13	6	3
1965	3	0	0
1966	1	0	0
1967	26	8	2
1968	8	4	0
1969	24	11	0
June 1970 to Nov. 1970	1	0	0
Feb. 1971	12	9	2
July 1971 to Dec. 1971	1	0	0
May 1972 to Dec. 1972	2	1	0
1973	14	7	1

NOTE 1. The table includes all periods of more than two months duration between October 1954 and December 1973 during which continuous recording was maintained.

2. On only three days between February 1955 and June 1974 did the river exceed the five metre level at St. Albans, viz. 13 May 1962, 29 April 1963 and 10 June 1964.

Based on data supplied by the N.S.W. Water Conservation and Irrigation Commission.

TABLE 3

ESTIMATED ANNUAL STREAMFLOW OF MACDONALD RIVER AT ST. ALBANS (million m^3)*

1904	166.5	1928	92.3	1952	404.5
1905	31.0	1929	164.7	1953	203.0
1906	9.6	1930	355.7	1954	96.0
1907	32.8	1931	287.1	1955	618.8
1908	244.8	1932	8.0	1956	442.6
1909	107.7	1933	24.8	1957	4.7
1910	102.6	1934	203.1	1958	108.8
1911	83.0	1935	7.6	1959	70.5
1912	63.0	1936	17.5	1960	29.5
1913	583.1	1937	33.2	1961	94.5
1914	62.0	1938	14.7	1962	269.5
1915	47.7	1939	26.9	1963	456.1
1916	36.4	1940	9.7	1964	189.6
1917	35.0	1941	11.5	1965	13.6
1918	32.3	1942	164.4	1966	4.2
1919	2.6	1943	91.0	1967	132.8
1920	78.3	1944	7.9	1968	38.1
1921	362.1	1945	174.8	1969	153.3
1922	142.7	1946	204.3	1970	36.3
1923	5.5	1947	51.9	1971	171.6
1924	16.8	1948	80.0	1972	117.7
1925	19.1	1949	504.4	1973	88.1
1926	202.9	1950	1154.4		
1927	288.5	1951	314.3	Average Annual Flow - 150.5	

* From New South Wales Department of Public Works, 1975, Table 12.

TABLE 2

CROSS-SECTION DATA FROM 19 SITES SHOWN ON FIG. 1B

Site No.	Valley Width	Channel Width	Bank Height	W/H Ratio	Low Bench Heights (Left/Right Banks)	Low Bench Widths (Left/Right Banks)	Bed Width	Slope Angle of Tallest Bank Segment (Left/Right Banks)
1.	350	78.94	3.25	24.3	1.08/.39	5.79/2.74	64.62	22/32
2.	420	108.51	3.35	32.4	1.25/---	7.92/---	80.16	23.5/21.5
3.	420	60.65	5.55	10.9	.41/---	10.97/---	27.12	24.5/25.5
4.	390	127.10	6.24	20.3	1.02/1.41	1.52/7.26	101.50	30/25.5
5.	340	104.24	7.33	14.2	1.64/.99	14.32/7.31	40.23	48/24.5
6.	340	101.80	7.98	12.8	3.06/1.86	6.25/3.35	53.64	19/23
7.	370	134.72	7.14	18.6	1.52/2.11	24.38/23.16	30.48	16/24.5
8.	1000	111.25	8.05	13.8	1.66/1.84	8.38/6.40	53.64	18.5/22.5
9.	330	142.65	7.76	18.3	.72/2.77	3.35/31.24	87.48	24.5/31
10.	270	99.97	6.42	15.6	1.75/2.07	28.50/10.82	43.90	34/26
11.	310	117.35	6.66	17.6	1.31/1.39	17.68/12.34	42.06	25/30.5
12.	215	98.75	6.35	15.5	1.75/2.12	5.79/3.35	54.25	22/16
13.	330	105.76	6.38	16.6	1.81/2.10	22.86/12.50	43.59	13.5/22
14.	245	102.11	7.08	14.6	1.42/2.05	17.37/33.83	37.49	5.5/34
15.	225	120.40	6.26	19.2	1.32/---	36.57/---	37.18	13/41
16.	500	134.72	6.89	19.5	---/.93	---/13.11	57.91	33/7.5
17.	177	128.93	7.21	17.88	.99/1.86	4.88/8.53	74.07	28.5/20.5
18.	205	123.13	6.55	18.80	1.56/1.36	10.97/16.46	44.50	10.5/13.5
19.	210	115.52	6.96	16.60	2.82/1.57	14.93/4.72	58.21	12.5/21.5

Linear measurements in metres. Slope angles in degrees.

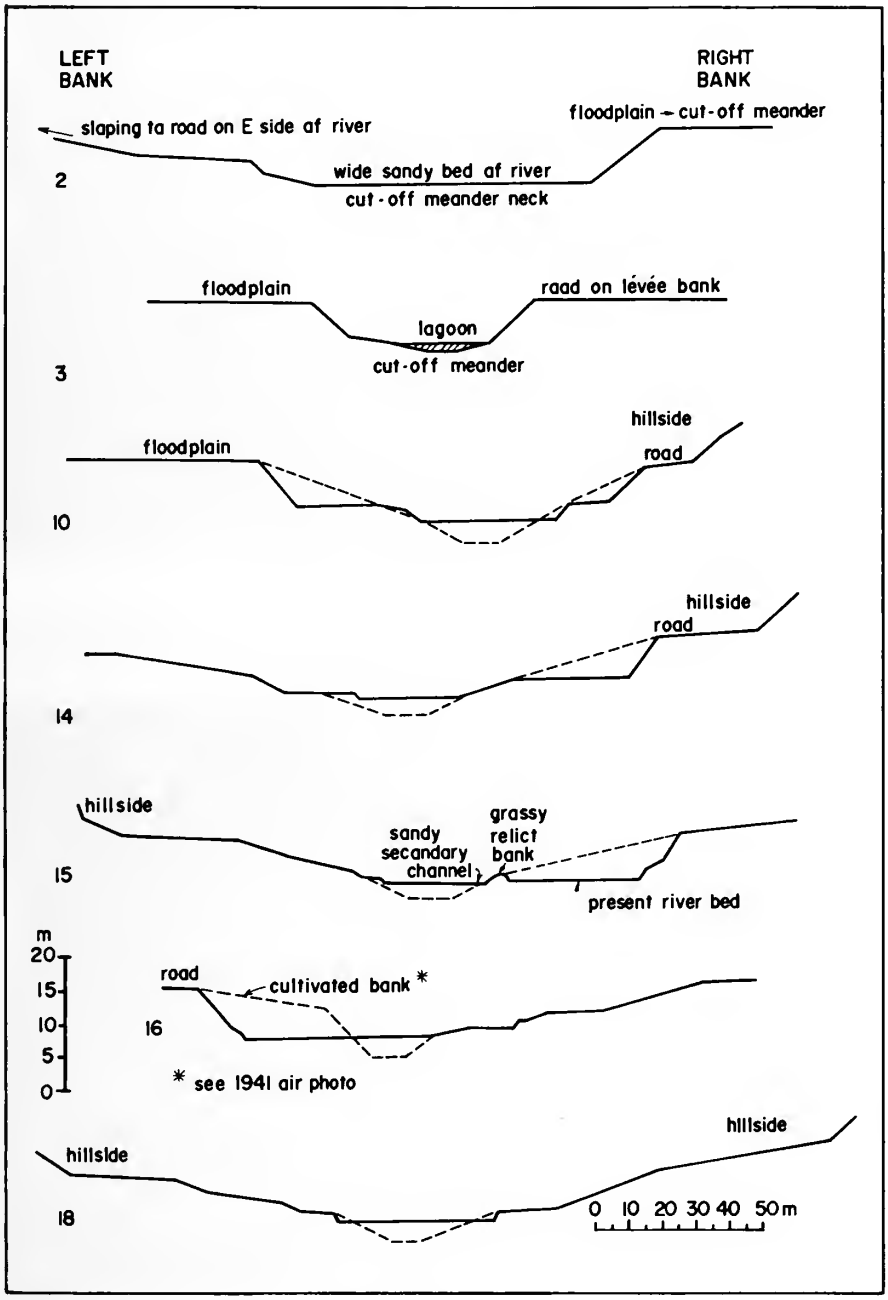

Figure 2. Cross-sections of channel at seven sites included in Table 3. The dashed lines showing pre-1949 profiles are based on information from local farmers.

PLATE 1

Macdonald River at St. Albans bridge about 1910 showing pre-1949 channel (Photograph by Mrs. E. Jurd)

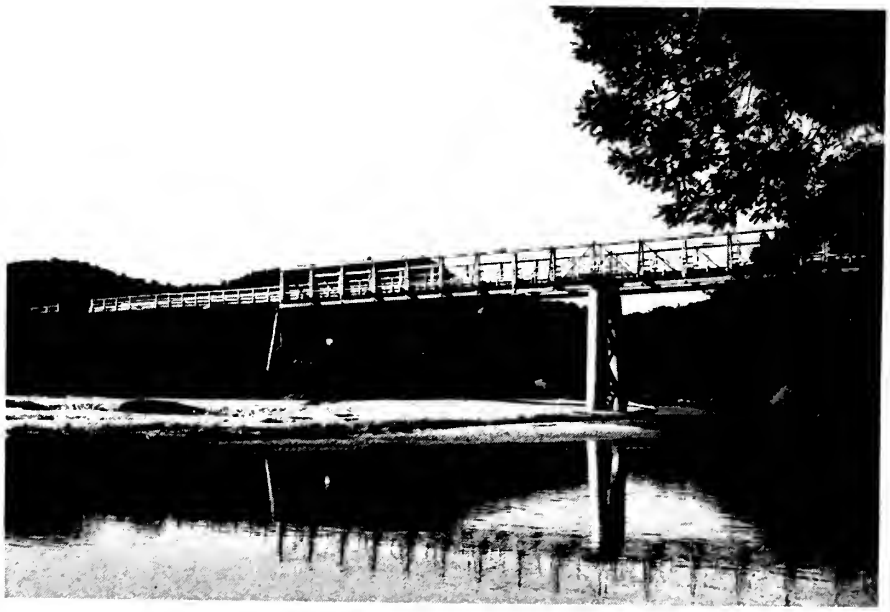

PLATE 2

Macdonald River at St. Albans in 1973 showing widened channel and aggraded bed (see bridge pylons).

PLATE 3

River meander 5 kilometres below St. Albans in 1925 (By courtesy Government Printing Office).

PLATE 4

Neck of cut-off meander in 1974 (this is the same meander illustrated in Plate 3).

PLATE 5

Sternbeck's since buried bridge at Higher Macdonald about 1940 (C. Sternbeck at approach to bridge). (Photograph by Mrs. O. Sternbeck).

PLATE 6

Site of Sternbeck's buried bridge in 1974 (the late K. Sternbeck is standing where C. Sternbeck stands in Plate 5.

PLATE 7

Aerial photograph of the Upper Macdonald River, 12 November 1971. Mellong area, run 4, No. 59537, reproduced by permission of the National Library of Australia and the Department of Lands, N.S.W.

PLATE 8

Macdonald River, Higher Macdonald area, in 1970. (By courtesy Dept. of Lands). Scale 1:14550.

ACKNOWLEDGEMENTS

The writer's thanks are due to the Macdonald River farmers for information, photographs and hospitality; to K. Cadogan and H. McCubbin of Prospect County Council for access to survey data from 1833 to the present; to officers of N.S.W. Water and Conservation Commission and the N.S.W. Department of Public Works for information; and to Professor J.L. Davies, Drs. R.J. Blong, P.J. Conaghan, W.N. Holland, G. Pickup S.J. Riley and M.A.J. Williams and to M.F. Clarke for invaluable advice and assistance. In conclusion the writer expresses his sorrow that Keith Sternbeck, field assistant and friend, and fourth generation farmer of Higher Macdonald, did not live to see this paper completed.

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(Manuscript received 3.9.76).

Journal and Proceedings, Royal Society of New South Wales, Vol. 110, pp. 17-24, 1977

Does the Hunter River Supply Sand to the New South Wales Coast Today?

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ABSTRACT. The possibility that terrestrial sand is being added to the open coast by the Hunter River was investigated by sediment sampling. Medium-fine quartz sand infills the lower 9.5 km of the Hunter estuary. This deposit is the product of a now largely inactive, landward transport of marine sand from the open coast. Lithic river sand of terrestrial origin occurs upstream of the marine sand and becomes finer in a seaward direction. Minor amounts of very fine river sand are admixed with coarser marine sand in the lower estuary. Superficial deposits of terrestrial mud also occur in those parts of the lower estuary that have been dredged. Very fine river sediment is periodically flushed out to sea by floods. It does not accumulate in the high energy nearshore environment but settles in deeper water further offshore. Under present day conditions the Hunter River does not contribute significant amounts of sand to the adjacent beaches or nearshore zone.

INTRODUCTION

One factor in the present day sediment budget of sandy shoreline deposits (or "sweep zone" of Davies 1974) is the supply of river sand to the coast and its addition to the beaches. Bowen and Inman (1966) have shown the importance of this factor in California, where the construction of dams on coastal rivers has reduced the contribution of terrestrial sand to the coast and caused a deficit in the sediment budget. In contrast, Ford (1963) suggested that rivers are not supplying sand to the New South Wales coast and "that the prevailing movement (of sand) is from the ocean into the entrances". Work by the Geological Survey of New South Wales in a number of estuaries in New South Wales (Roy and Peat, 1973 and 1975 a, b and in press) supports Ford's conclusion. On the New South Wales coast, the composition and texture of the estuarine sands have been found to be a useful indicator of their source, whether marine or terrestrial. Most of the New South Wales studies, however, were of estuaries with relatively small river inflows. The possibility therefore exists that, during floods, larger coastal rivers may carry terrestrial sand to the sea.

The present day distribution of sediments in the coastal zone reflects processes operating during the Late Quaternary (Roy and Thom 1975). Throughout this time, processes were strongly influenced by glacio-eustatic events (Chappell 1974), especially the last two sea level fluctuations. During the most recent rise in sea level (the Post-glacial Transgression which culminated in the sea reaching its present level about 6,000 years ago - Thom and Chappell 1975) the coastal river valleys were drowned to form estuaries. There followed a phase of estuary infilling by both marine and fluvial processes. Marine sediments formed coastal barriers and tidal deltas in the estuary mouths, while river sediments were deposited in the central and upper reaches of the estuaries. During this phase of estuary infilling, the supply of terrestrial sand to the coastline is negligible. The stage of infilling reached today is mainly a function of the sizes of the original embayments and the supply of river detritus, the latter being related to river discharge. Many of the coastal rivers, especially the larger ones, have almost completely infilled their embayments with river sedments (producing flood plains) which have prograded over older estuarine and marine deposits. Davies (1974) argued that once the estuary is filled with sediment, river sand may be transported through the flood plain and delivered to the coast. However, river sand, to be deposited in the shallow nearshore zone and incorporated in the beaches, must be sufficiently coarse grained to attain dynamic equilibrium with the high-energy wave conditions of the open coast. The Hunter River, with its well developed flood plain, may have reached this stage.

This report summarizes the results and conclusions of an investigation of the sediments in the lower Hunter River designed to explore the possibility that it currently supplies sand to the coast.

The Hunter River is located 120 km north of Sydney. It is the fifth largest river (in terms of discharge) on the New South Wales coast with an average discharge of approximately 58 m^3/sec (2000 cusecs) (Water Conservation and Irrigation Commission of N.S.W., 1971). The river is tidal for a distance of approximately 55 km from its mouth (Department of Public Works, N.S.W., tidal data, 1956 - plan 201/141). The port for Newcastle, the second largest city in N.S.W., lies at the mouth of the Hunter River. Breakwaters and port facilities have been constructed, and the lower estuary has been dredged since 1905 (King 1911) to reclaim land and improve navigation. Consequently, much of the river bed in the port area reflects man's interference.

SAMPLING

Surface sediments were dredged at forty-three sites in the river channel between the river mouth and Raymond Terrace, 30 km upstream. Two samples were collected from Newcastle Bight outside the harbour mouth and two samples were taken from

* This paper was submitted with the permission of the Under-Secretary, New South Wales Department of Mines.

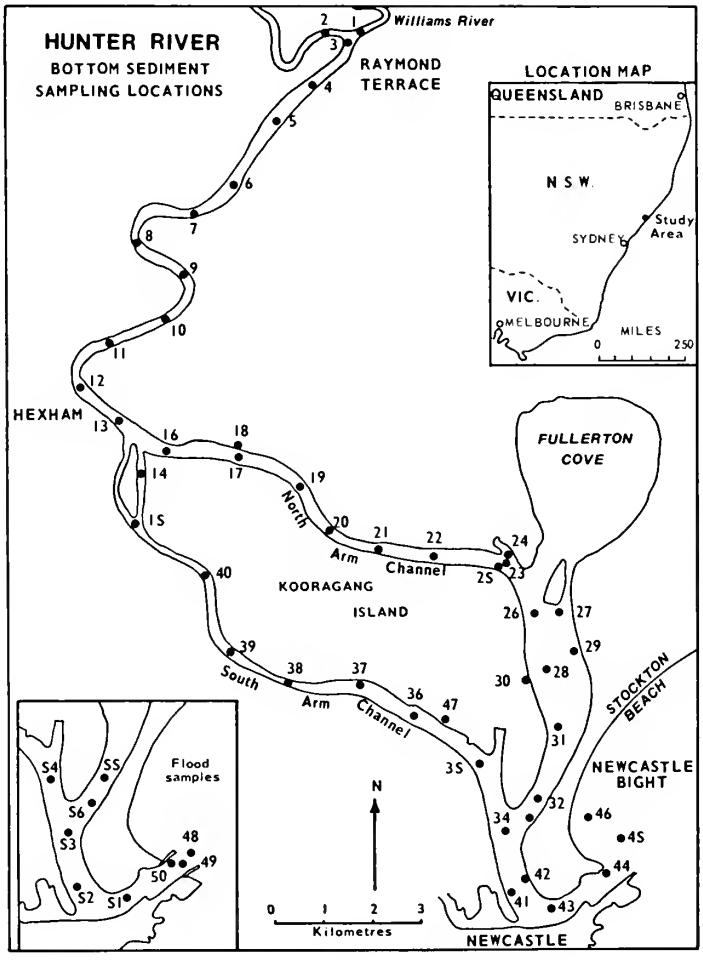

Figure 1. Bottom sediment sampling locations in the lower Hunter River.

TABLE 1

HUNTER RIVER AND NEARSHORE SEDIMENTS -
SAMPLE COMPOSITION AND SOURCE (OF SAND COMPONENT)

CLEAN SAND 10% MUD	MUDDY SAND 10-50% MUD	SANDY MUD 50-90% MUD	MUD 10% SAND
2 (T) 26 (M*)	13 (T)	1 (T)	3 (T)
4 (T) 27 (M*)	17 (T)	18 (T)	35 (T)
5 (T) 30 (M)	20 (T)	24 (T*)	36 (T)
6 (T) 31 (M*)	21 (T)	32 (T)	42 (T*)
7 (T) 33 (M*)	22 (T)	34 (T)	
8 (T) 37 (M*)	29 (M*)	43 (T)	49 (T)
9 (T) 38 (M*)			54 (T)
10 (T) 41 (M*)	50 (M*)	48 (T)	55 (T)
11 (T) 44 (M)	52 (T*)	51 (T*)	56 (T)
12 (T) 45 (M)		53 (T)	
14 (T) 46 (M)			
15 (T) 47 (M)			
16 (T)			
19 (T)			
23 (T*)			
25 (T*)			
28 (T*)			
39 (T*)			
40 (T)			

28 = sample location (Figure 1)
(T) = terrestrial sand
(M) = marine sand
(T*) = mainly terrestrial with minor marine sand
(M*) = mainly marine with minor terrestrial sand

(N.B.: Mud component in sediment is of terrestrial origin)

dredge spoil dumps on Kooragang Island. At a later date nine additional samples were collected near the estuary mouth 2 days after the peak of a 1 in 3 year flood. The flood reached Maitland, 45 km upstream of Newcastle, on the 26th January, 1976; it resulted in a 10 m rise in river level and a maximum discharge of 173,000 mega l/day (J. McGlyn, W.C. and I.C., pers. comm.). Sample locations are shown in Figure 1. Also examined were drill hole samples from beneath Newcastle Harbour supplied by Coffee and Hollingsworth Pty. Ltd. and Dames and Moore Pty. Ltd., consulting engineers. Sediment data from Stockton Beach were provided by Cheng Ly (Department of Geology, University of Newcastle, pers. comm.) and A. Gordon (P.W.D., pers. comm.).

Sand:mud (silt plus clay) ratios were determined and the sands were examined under a binocular microscope to estimate composition and texture. Detailed granulometric analyses were carried out on samples 1 to 47 by Cheng Ly (Ly, in prep.). Standard grainsize analysis of samples 48 to 56 was undertaken by the P.W.D. Hydraulics and Soils Laboratory. The samples are described in the appendix.

SEDIMENT TYPES

Grain size is largely a function of the depositional energy level. Very muddy sediments accumulate under quiet conditions; clean sand indicates higher energy levels. Clean sand (less than 10 per cent mud) comprises 56 per cent of the samples, muddy sand (10 to 50 per cent mud) comprises 14 per cent, sandy mud (50 to 90 per cent mud) comprises 16 per cent, and mud (less than 10 per cent sand) comprises 14 per cent.

The composition and texture of the sand grains indicate the source of the sediment, whether terrestrial or marine. Marine sand, typified by that occurring on the ocean beach, is composed of medium sized, subrounded to well rounded quartz grains with less than 20 per cent lithic fragments; shell fragments are always present. River sand is composed of terrestrial detritus rich in lithic (rock plus feldspar) fragments; lithic content ranges from 50 to 70 per cent. Grains are angular to subangular and vary in grainsize from coarse to very fine. Shell fragments occur rarely and, in the Hunter River, were only found in samples seawards of Hexham. The heavy mineral suite in the marine sediment is dominated by rutile, zircon, ilmenite and leucoxene. In contrast, the river sediment is characterised by pyroxene, hornblende, epidote and magnetite (Ly in prep.)

The samples are categorized in Table 1. All muds, sandy muds and, with two exceptions (samples 29 and 50) muddy sands, are composed dominantly of terrestrial material. Of these twenty-five samples, four contain traces of marine sand (samples 24, 42, 51 and 52), while the sand in

samples 29 and 50 is predominantly marine. The remaining thirty-one samples are clean sands of which fifteen are of terrestrial origin, and five are of marine origin. The remaining eleven samples contain mixed marine and terrestrial material; of these seven are mainly marine and four are mainly terrestrial.

SEDIMENT DISTRIBUTION

The sediments sampled in the lower Hunter River in the pre-flood period fall into two groups that occupy different parts of the estuary. (The sediment distribution altered somewhat during the flood and is described later). Downstream from Raymond Terrace, river sediments occupy the channel to within 9.5 km of the sea. Seawards of this point sediments of marine origin dominate in the Hunter estuary and occur on the ocean beach and off the river mouth (Figure 2).

Clean or muddy river sand is the dominant sediment type downstream of Raymond Terrace as far as the mouth of Fullerton Cove in North Arm Channel and almost half-way down the length of Kooragang Island in South Arm Channel. Mud or sandy mud occurs only rarely in this sector. A superficial layer of mud occurs in a 19 m deep scour hole at the junction of the Hunter and Williams Rivers. Sandy mud was found in the bed of the Williams River (sample 1) and at two sites near the bank of North Arm Channel (samples 18 and 24).

The river sands show a progressive decrease in grainsize from medium - fine to very fine in a downstream direction. This grainsize trend is most apparent in North Arm Channel. In South Arm Channel the sands are slightly coarser, indicating a somewhat higher energy regime. Downstream oriented sand waves occur commonly above Kooragang Island and indicate a downstream direction of sediment transport during the ebb tidal flow as well as during river floods.

The sediment in the lower 9.5 km of the estuary is mainly clean or slightly muddy marine sand which incorporates, as a minor component, very fine river sand. Clean, medium-grained marine sand (with no trace of a river component) was found offshore (samples 45 and 46) and also in dredge spoil on Kooragang Island (samples 30 and 47). The marine sands in the estuary are virtually identical in composition and texture to those in the nearshore zone and on Stockton Beach.

As well as marine sand, mud and sandy mud were also encountered in the harbour area. The sand component of these muds is very fine grained and is of terrestrial origin. Drilling in the harbour area penetrated up to 8 m of soft mud and fine sandy mud in parts of the channel that have been deepened by dredging. Shelly marine sands occur beneath the mud in these areas and overlie a stiff, weathered clay deposit of Pleistocene age.

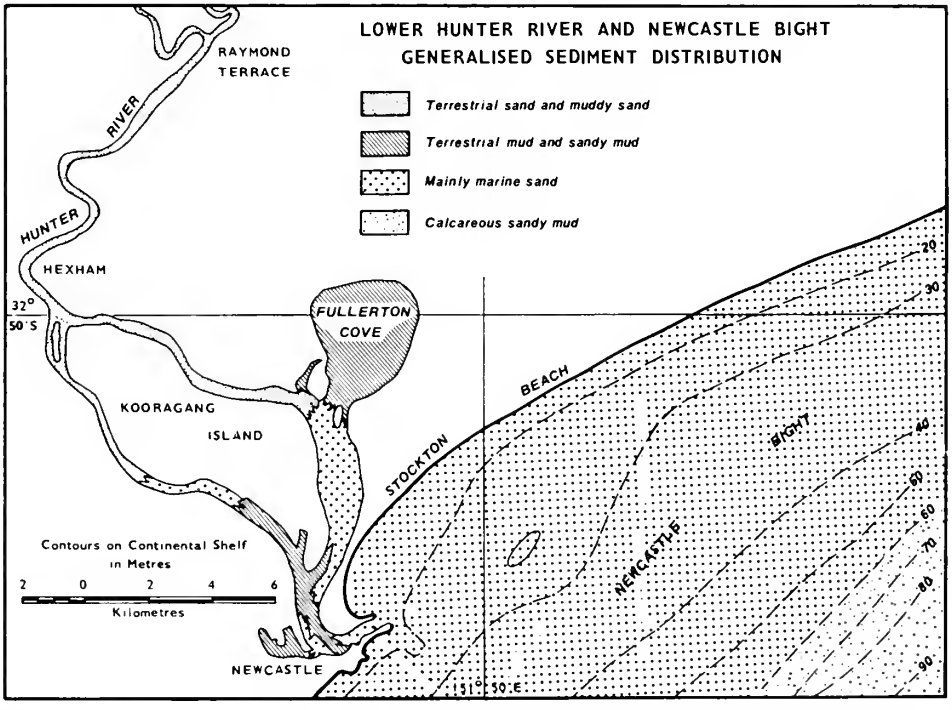

Figure 2. Generalised sediment distribution in the lower Hunter River and Newcastle Bight.

DISCUSSION

The predominance of sand sized sediment in the Hunter River estuary is characteristic of a depositional environment with moderately high energy levels. The sand in the upstream part of the estuary is of terrestrial origin. Its progressive fining in a downstream direction suggests a sorting mechanism associated with its gradual seaward transport. Its texture is thought to reflect normal estuarine conditions (tidal and river flow) rather than catastrophic events such as floods.

A marked difference exists between the composition of the sediments in the Williams River (sandy mud) and the Hunter River (sand) immediately above their junction. Because of its greater catchment area and discharge, the Hunter River is the major contributor of terrestrial sand to the estuary, while the much smaller Williams River mainly supplies mud. The composition of the marine sand in the lower reaches of the estuary, especially the presence of estuarine shell species, indicates an estuarine channel or tidal deltaic environment of deposition. The shelly marine sands encountered by drilling beneath the dredged bed of the harbour belong to the same depositional unit.

Tidal currents and waves are mainly responsible for the landward movement of marine sand from the open coast into the estuary mouth, although aeolian processes may have contributed some sand from the adjacent dunes at Stockton in the past. Fluorescent tracer tests conducted in Newcastle Harbour mouth by the P.W.D. (Boleyn and Campbell 1966) showed no evidence that marine sand was moving into the river mouth during the period of testing. The marine sand in the lower estuary is presumably a relict deposit, although still being reworked by currents at present. A compositional difference appears to exist between the surface and subsurface marine sands in the lower estuary: superficial samples contain a minor component of fine terrestrial sand, while sand dredged from beneath the channel bed and used to reclaim Kooragang Island is completely free of terrestrial sand (compare samples 26, 28, 30, and 37 from the river bed with samples 30 and 47 of spoil dredged from subsurface). This upward change from marine to more terrestrial sediment is in accord with the geological model of estuary infilling proposed above and reflects the gradual seaward migration of terrestrial sediments over older marine deposits.

Siltation studies in Newcastle Harbour by the P.W.D. (1969) indicate that shallow areas, such as Fullerton Cove, act as settling basins for suspended sediment during floods. The mud is remobilized by wave turbulence during non-flood periods, and currents redistribute it throughout the port area. Here it accumulates under low-energy conditions in navigation channels and docks that have been deepened by dredging. These dredged areas act as traps for sediment moving seaward down the channels. Samples of mud collected in the port area contain traces of fine terrestrial sand indicating that some fine river sand is transported into the lower estuary. However, the almost complete absence of medium-grained river sand in the mud, even at depth, suggests that very little sand of this size is reaching the estuary mouth. (By the same reasoning it would also appear that little marine sand from the open coast is moving landwards up the river channels).

TABLE 2

COMPARISON BETWEEN PRE-FLOOD AND FLOOD SAMPLES FROM THE LOWER HUNTER RIVER
(SAMPLE LOCATIONS SHOWN IN FIGURE 1)

Pre-Flood		Flood	
35	Mud	54	Mud
32	Sandy Mud	55	Mud
33	Mainly marine Sand	56	Mud
34	Very sandy Mud	53	Sandy Mud
41	Mainly marine Sand	52	Mainly muddy lithic Sand
43	Sandy Mud	51	Slightly sandy Mud
44	Marine Sand	49	Mud
		50	Mainly muddy marine Sand
		48	Sandy Mud
45	Marine Sand		

Undoubtedly fine sediment in the lower Hunter River is flushed out to sea during floods. Samples collected near the river mouth during the flood in January 1976, when compared with pre-flood sediments from similar sites, show an increase in mud content and contain more fine to very fine river sand (see Table 2). The medium to coarse sand in some samples is predominantly marine in composition and is presumably derived from reworking of marine deposits in the lower estuary. The presence of this mainly fine sediment on the channel bed, despite the undoubtedly higher than normal current velocities, reflects a disequilibrium between the sediments and the hydrodynamic processes and confirms a seaward transport of sediment under these conditions. However, sediment transport under extreme flow conditions (ie. 1 in 100 year flood) cannot be extrapolated with confidence from this data.

On Stockton Beach and in the nearshore zone, energy levels are too high for fine sand and mud to accumulate. Here the beach sands range from medium to coarse grained. Fine river sediment presumably moves farther offshore and is deposited in deeper water where energy conditions are sufficiently low. Sampling on the inner continental shelf off Newcastle by Shirley (1964), the Bureau of Mineral Resources (Davies and Marshall 1972) and Boyd (1974) has delineated a zone of carbonate-rich mud and sandy mud between water depths of 60 m and approximately 120 m, lying seawards of a nearshore zone of clean quartz (Figure 2). Boyd reasoned from grainsize data that the Hunter is the source of the shelf mud. An association between the sandy mud in the Hunter River and that on the continental shelf is supported by the mineralogical similarity of their clastic fraction (Byrnes and Holmes 1975). However, the question of when the shelf mud was deposited is

unresolved. The possibility that the shelf mud was derived from the Hunter River in the past and accumulated as estuarine deposits during period(s) of lowered sea level cannot be discounted on sedimentological evidence alone (Davies and Boyd 1975).

The composition of the sand forming Stockton Beach provides further data on the possible input of terrestrial sand to the coast. Studies by the P.W.D. (A. Gordon pers. comm.) show no evidence of a net littoral drift along the beach. Consequently, a significant input of terrestrial sand would be expected to produce a recognizable change in beach sediment near the river mouth. Detailed granulometric and mineralogical analyses of beach sands by Cheng Ly show a number of trends:

(i) The proportion of angular and very angular grains increases at the northeastern end of the beach.

(ii) Lithic content increases slightly at both extremities.

(iii) Heavy minerals are typically marine in character except at the northeastern end of the beach where 'terrestrial' minerals such as pyroxene, hornblende, epidote and magnetite are dominant.

The changes at the northeastern end of the beach are attributed to marine erosion of nearby Carboniferous volcanic rock outcrops. At the southwestern end of the beach however, the absence of parameters characterizing river sediment (ie., significant quantities of terrestrial heavy minerals, angular grains, and rock fragments) is regarded as evidence against a significant supply of river sand to the coast.

CONCLUSION

Relict deposits of shelly, quartz-rich marine sands occur in the lower 9.5 km of the Hunter River estuary. These deposits were derived from the open coast and transported into the river mouth by waves and tidal currents during, and since, the Post-glacial Transgression. It is probable that this process is no longer active.

Lithic river sands, derived mainly from the Hunter River rather than from the Williams River, occur in the upper estuary landwards of the marine sands. Sorting processes associated with the slow seaward transport of the river sand are thought to be responsible for its progressive fining in a downstream direction. Minor amounts of very fine river sand occur in deposits of mud and in the surface layer of the marine sand in the lower estuary. However in the subsurface, marine sands contain virtually no terrestrial material. This upward change in composition is probably the result of the gradual seaward progradation of younger fluvial deposits over marine sediments as the Hunter River estuary infills. To date the infilling process is incomplete. Under present day conditions, mud and very fine river sand accumulate in the lower estuary and are periodically flushed out to sea by river floods. The high-energy conditions in the nearshore zone preclude the deposition of this river sediment which is presumably carried further offshore and deposited in deeper water.

The absence of a significant build up of river sediment in Stockton Beach near the river mouth is further evidence against a significant supply of medium-grained river sand to the coast in the recent past.

Historical studies of shoreline changes along Newcastle Bight indicate a general erosional trend (B.G. Thom, University of Sydney, pers. comm.). The loss of beach sand is mainly attributed to aeolian processes and the inland migration of mobile transgressive dunes. In terms of sediment budget, erosion of Stockton Beach reflects an imbalance between gains and losses of sand to the coastal compartment. This study argues that the budget imbalance is at least partly due to the inability of the Hunter River to supply significant quantities of terrestrial sand to the coast.

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APPENDIX

SAMPLE DESCRIPTIONS

Sample	Composition (%)				Texture of Sand Fraction		
	Mud	Terrestrial Sand	Marine	Shell & Wood	Grainsize	Sorting	Angularity
1	80	19	0	1	vf-m	P	A
2	10	89	0	1	f-m	M	A
3	100	0	0	0	-	-	-
4	0	100	0	0	m	MW	SA
5	3	97	0	0	f-m	MP	A-SR
6	0	100	0	0	f	MW	S-SR
7	2	96	0	2	m	W	A-SR
8	0	100	0	0	f	MW	SA
9	0	100	0	0	f-vf	VW	A
10	3	97	0	0	f	W	A
11	4	96	0	0	f	MW	A-SA
12	10	90	0	0	f	MW	A-SA
13	40	60	0	0	f-vf	P	A
14	3	92	0	5	f-m	P	A-SR
15	0	90	0	10	f-c	P	SA-SR
16	5	95	0	0	f	W	A-SA
17	18	82	0	0	f	VW	A-SA
18	80	17	0	3	vf	W	A
19	3	96	0	1	f	W	A-SA
20	30	65	0	5	f-vf	MW	A-SA
21	20	75	0	5	f-vf	W	A
22	40	57	0	3	vf	W	A
23	10	18	2	70	f-vf	MW	SA
24	80	13	4	3	f-vf	MP	A-SR
25	10	88	1	1	f-vf	W	A-SA
26	0	18	70	12	f-m	MP	SA-WR
27	0	5	80	15	m	M	R-WR
28	10	70	12	8	vf-m	P	A-SA
29	15	5	70	10	f-m	MP	SR-R
30	0	0	99	1	f-m	M	SR-WR
31	2	7	85	6	f-m	M	SR
32	70	25	0	5	vf	VW	A
33	0	10	74	16	m-c	MP	R-WR
34	50	40	0	10	vf	VW	A
35	98	2	0	0	vf	MW	A
36	98	2	0	0	vf	W	A
37	0	5	93	2	m	MW	SR-R
38	2	48	48	2	m	MW	SA-R
39	5	46	46	3	f-m	M	A-R
40	3	95	0	2	f	M	A-SA
41	5	25	65	5	f-m	MP	SA-R
42	95	3	1	1	vf	W	A
43	50	35	0	15	vf	M	A
44	3	2	70	25	f-m	P	SR-WR
45	0	0	97	3	f-m	W	SR-WR
46	0	0	90	10	f-m	MW	SR-R
47	0	0	100	0	m	MW	SR-R

Sand Textural Symbols

Grainsize

vf - very fine
f - fine
m - medium
c - coarse

Sorting

P - poorly
MP - moderately poorly
M - moderately
MW - moderately well
W - well
VW - very well

Angularity

A - angular
SA - subangular
SR - subrounded
R - rounded
WR - well rounded

APPENDIX (CONTINUED)

FLOOD SAMPLES

Sample	Composition (%)				Texture of Sand Fraction		
	Mud	Terrestrial Sand	Marine	Shell & Wood	Grainsize	Sorting	Angularity
48	87	8	0	5	f-m	P	A-SA
49	94	3	0	3	f	MW	A-SA
50	25	10	58	7	f-c	P	SA-R
51	90	2	6	2	f-m	P	SA-SR
52	19	44	23	14	f-c	P	A-R
53	77	20	0	3	f-m	P	A-SA
54	98	2	0	0	vf	W	A
55	96	3	0	1	vf	MW	A
56	98	2	0	0	vf	W	A

Sand Textural Symbols

Grainsize		Sorting		Angularity	
vf	very fine	P	poorly	A	angular
f	fine	MP	moderately poorly	SA	subangular
m	medium	M	moderately	SR	subrounded
c	coarse	MW	moderately well	R	rounded
		W	well	WR	well rounded
		VW	very well		

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(Manuscript received 11.10.76)

Journal and Proceedings, Royal Society of New South Wales, Vol. 110, pp. 25-27, 1977

A Late Devonian Palaeomagnetic Pole for the Mulga Downs Group, Western New South Wales

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ABSTRACT. The thermal stability of the magnetism in specimens from fourteen oriented core samples of red-beds belonging to the Mulga Downs Group was satisfactorily tested using the progressive partial thermal demagnetization technique up to 620°C. Magnetic remanence considered primary and acquired at the time of rock formation was isolated in twenty-one specimens from twelve samples: they yield a palaeomagnetic pole situated at 54°S, 96°E (A_{95} = 11°). This supports an earlier result obtained from the Middle Devonian Housetop Granite of Tasmania but differs substantially from results obtained from the Lochiel Formation of southeastern New South Wales. The result from the Mulga Downs Group is interpreted as emphasizing the discrepancy between the Palaeozoic palaeomagnetic results from the main Australian platform, and those from the Lachlan Fold Belt.

INTRODUCTION

Palaeomagnetic investigations of Early Palaeozoic rock formations have provided us with considerable data on which to base apparent polar wander models for the main platform of the Australian continent. Those data and some interpretations have been reported by McElhinny and Luck (1970), Luck (1972), Embleton (1972a,b), Embleton and Giddings (1974) and McElhinny and Embleton (1974). In addition, results obtained from Siluro-Devonian rock formations sampled in the southeastern region of Australia, reported by Briden (1966) and Luck (1973), have been interpreted within the framework of the plate tectonic hypothesis. McElhinny and Embleton (1974) and Embleton *et al.* (1974), following the earlier interpretations of the tectonic evolution of the Tasman Orogenic Zone by Oversby (1971), Solomon and Griffiths (1972) and Scheibner (1972), postulated that a region in southeastern Australia (the southern part of the Canberra-Molong High) though still rather poorly defined has undergone rigid rotation with respect to the main platform. Serpentinites which outcrop in a 'belt' from Kiandra in the south (the Coolac Serpentinite, Ashley *et al.*, 1971) and northward to Nyngan were regarded as a possible remnant of the Late Palaeozoic (Devonian?) suture. On the plate tectonic model, basic and ultrabasic rocks associated with serpentinites may represent fossil oceanic crust emplaced originally as ophiolite (Coleman, 1971) during a period of either subduction or obduction (Dewey and Bird, 1971). Much of the interpretation was carried out by matching the Siluro-Devonian palaeomagnetic pole positions for the main platform and southeastern regions.

A recent alternative model by Burns and Embleton (1976) explains the discrepancy in the palaeomagnetic data between the main Australian platform and the southeastern region in terms of internal deformation within the Lachlan Fold Belt, without attaching specific significance to the presence of the ultramafic and serpentinite bodies.

The significance of the pole position obtained by Briden (1967) from the Middle Devonian Housetop Granite of Tasmania was uncertain within the plate tectonic scheme. It was originally claimed that the granite had suffered a Tertiary remagnetization, although McElhinny and Embleton (1974) have given an equally plausible explanation of the magnetization being of Devonian age. Support for that pole position now comes from some Upper Devonian sediments from western New South Wales. How these data fit the palaeomagnetic drift scheme remains uncertain, they in fact may emphasize the over-simplicity of the McElhinny-Embleton model. The results do serve to reinforce the principal thesis that the configuration of the Devonian geomagnetic field varies considerably from south-eastern regions to regions further west.

PALAEOMAGNETIC RESULTS

Oriented rock samples were collected using techniques described by Collinson *et al.* (1967, Chap. 1) from three localities in western New South Wales: (i) seven block samples from a section through conglomerates and coarse-grained white/grey sandstones at Mount Manara, about 60 km north of Ivanhoe, (ii) five block samples from a section of white and buff-coloured medium-coarse sandstones at the southern end of the Manara Hills, about 15 km southwest of Mount Manara, and (iii) fourteen core samples collected with a portable hand drill from a 20-30 m escarpment outcrop about 8 km northeast of Milton Grove Station (latitude 32.8°S, longitude 143.5°E). Only samples from locality (iii) retained measureable stable components of magnetization. None of the samples from localities (i) and (ii) produced repeatable results upon partial thermal demagnetization.

The beds sampled near Milton Grove Station trend approximately east-northeasterly at 65° and dip to the northwest at 30°. This sequence of red sediments belongs to the Mulga Downs Group, generally regarded as Late Devonian in age. Roberts *et al.* (1972) cite evidence from Ritchie (1969) which supports a Middle Devonian age for the lower part of the succession. The highest beds may be as young as Early Carboniferous.

Two specimens were cut from each core and

TABLE 1
SUMMARY OF DIRECTIONS OF REMANENT MAGNETISM FOR SEDIMENTS OF THE MULGA DOWNS GROUP

Treatment	Dec°	Inc°	N	R	k	α_{95}°
NRM	041	-65	28	22.60	5.0	13
300°C	041	-61	28	22.48	4.8	14
400°C	042	-62	28	22.52	4.9	14
500°C	044	-61	28	22.26	4.7	14
550°C	051	-60	28	22.89	5.2	13
600°C	056	-75	28	19.14	3.0	19
620°C	047	-67	28	19.83	3.3	18

Pole position based on the mean of 21 specimen virtual geomagnetic poles calculated after treatment at 550°C (see text): N = 21, R = 19.87, Dec = 042, Inc = -67, α_{95} = 8°, Lat. = 54°S, Long. = 96°E, A_{95} = 11°.

NRM - natural remanent magnetization,
Dec - declination,
Inc - inclination,
N - number of unit vectors of which R is the resultant,
k - the Fisher (1953) precision parameter, and
$\alpha_{95}(A_{95})$ - the semi-angle of the cone of confidence calculated at the 95% probability level (P - 0.05).

their directions and intensities of remanent magnetism measured before treatment (NRM in Table 1) and after partial thermal demagnetization at six steps between 300°C and 620°C. The step-wise thermal demagnetization technique is described in Collison *et al.* (1967, Chap. 3). Specimen directions of magnetization were shown to change little upon treatment and the intensity of magnetization decreased smoothly (see Fig. 1) as would be expected for a fairly stable magnetic component. Table 1 lists the statistics (following Fisher, 1953) for each population obtained after successive stages of thermal demagnetization. The scatter marginally decreased at 550°C, although no statistical significance is attached to that. However, several specimens remain oblique to the principal population and those at an angular distance > 45° from the group mean (see Fig. 2) are considered intermediate and have probably retained substantial components of secondary magnetization: they were omitted from further calculations. Specimens from two samples were oppositely magnetized; they were inverted to obtain mean directions for the group. Before the bedding correction was applied, the mean direction of magnetization, dec. = 6°, inc. = -46°, α_{95} = 8°, was significantly different (18.1°) from the local present field direction, dec. = 9°, inc. = -64°, though the difference between the mean and the dipole field direction, dec. = 0°, inc. = -52° was only 7.2° (calculated for the 95% confidence level of the mean). However, the presence of a polarity reversal in the rock sequence is strong evidence for the stability of magnetization and that it is primary. Specimen virtual geomagnetic poles were averaged to yield the formation palaeomagnetic pole position: it lies at 54°S, 96°E (A_{95} = 11°).

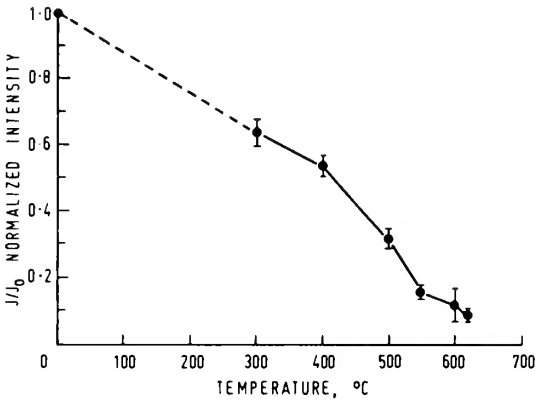

Figure 1. The average demagnetization-intensity curve for the Mulga Downs Group red sediments. The bars indicate the standard error of the mean intensity obtained after treatment at the temperatures indicated.

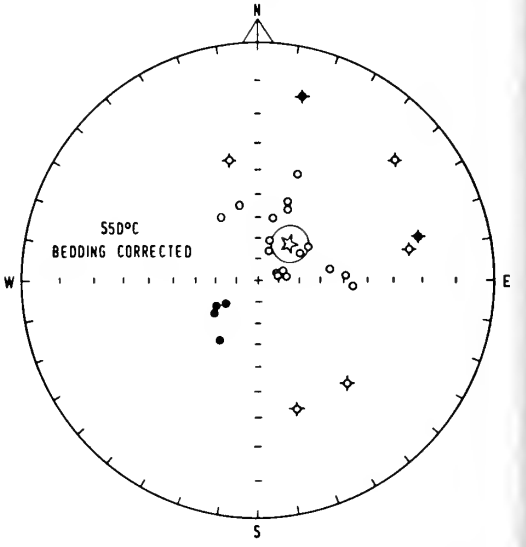

Figure 2. The distribution of specimen directions after partial thermal demagnetization at 550°C. Those directions distinguished with a cross lie > 45° from the population mean (indicated by an open star). A stereographic (equal angle) projection is used, open (closed) symbols denote upward (downward) pointing directions. The circle of confidence for the 95% probability level is also shown. The primitive represents the bedding plane.

TECTONIC IMPLICATIONS

The result is consistent with an earlier result for the Devonian obtained by Briden (1967) from a study of the Housetop Granite of Tasmania, viz. 67°S, 94°E. Embleton and Giddings (1974) have previously suggested that Tasmanian rock formations provide palaeomagnetic data which relate to the main platform of Australia. For example, the pole yielded

by the Upper Cambrian Dundas Group (Briden, 1967) falls in a group of Cambro-Ordovician poles obtained from localities widely spread across the continent. However, Siluro-Devonian rock formations in the southeastern mainland region of the Tasman Orogenic Zone yield results which have been regarded as contrary to a pattern of tectonic evolution based on the premise of a 'unified continent' during the Early and mid-Palaeozoic era.

The model proposed by McElhinny and Embleton (1974) and detailed by Embleton *et al.* (1974) implies suturing along a line east of the Wagga Metamorphic Belt sometime during the Devonian. The presence of relatively undisturbed Upper Devonian sediments in the region of the Bogan Gate Platform would further suggest that tectonic events affecting the area were more or less completed before sedimentation. Thus, on the plate tectonic model, the apparent inconsistency between the Late Devonian poles from (a) the Mulga Downs Group (presented here) and (b) the Lochiel Formation sampled in the vicinity of Nethercote (pole position is 320°E, 58°S) suggests the development of a protracted period of relative 'block' motion which ultimately involved the most easterly regions. The geological evidence on which the Burns and Embleton (1976) model is based, explains the post-Late Devonian relative movement between approximately the Wagga Metamorphic Belt and the eastern coastal regions in terms of a Kanimblan (Early Carboniferous) deformation across the whole of eastern New South Wales.

ACKNOWLEDGMENTS

The samples were collected while the author was a faculty member of the Research School of Earth Sciences, Australian National University, with the assistance of Dr M.W. McElhinny, Mr C. Barton and a visiting fellow Dr R. Merrill, from the State University of Washington, Seattle, USA. Measurements were carried out in the Canberra laboratories with the kind permission of Professor A.L. Hales, Director of the School.

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(Manuscript received 24.3.1976)
(Manuscript received in final form 20.9.1976)

Journal and Proceedings, Royal Society of New South Wales, Vol. 110, pp. 29–31, 1977

Series of Roots of a Transcendental Equation

PIETRO CERONE AND AUSTIN KEANE

ABSTRACT. Series arising from the solution of a differential-difference equation are summed by the use of Laplace transform methods and residue theory. The terms of the series depend on the roots of the transcendental equation $p = e^{-\eta p}$, where $\eta > 0$.

INTRODUCTION

Silberstein (1940), sums series arising from the solution of the differential-difference equation

$$\begin{aligned} u'(t) &= u(t-\eta) , \quad t > \eta , \\ u(t) &= g(t) , \quad 0 \leq t < \eta . \end{aligned} \tag{1}$$

Taking the particular value $g(t) = 1 + t$, Silberstein obtains the solution to (1), by the use of analytic continuation and an "orthogonality" condition, in the form:

$$u(t) = \sum_{p_j} \frac{e^{p_j t}}{p_j(1 + p_j \eta)} \tag{2}$$

where the p_j's are the roots of the characteristic equation $h(p) = 0$,

$$h(p) = p - e^{-\eta p} \tag{3}$$

and the sum is over all p_j . From here on we will not specifically denote summation over p_j .

Then with the condition

$$u'(\eta) = u(0) \tag{4}$$

holding, Silberstein concludes that (with $\eta = 1$)

$$\sum \frac{1}{p_j(1 + p_j)} = u(0) = 1 \tag{5}$$

and

$$\sum \frac{1}{p_j^2(1 + p_j)} = u(1) = 2 . \tag{6}$$

It will be shown in this paper that condition (4) need not hold to obtain series identities by use of Laplace transform methods.

It should be kept in mind that differing values of η result in different values of the p_j .

SOLUTION OF THE DIFFERENTIAL-DIFFERENCE EQUATION

Many authors including Bellman and Cooke (1963) and El'sgol'ts and Norkin (1973), have solved (1) by use of Laplace transform techniques, the solution being given by

$$u(t) = \lim_{R\to\infty} \frac{1}{2\pi i} \int_{\gamma-iR}^{\gamma+iR} e^{pt} f(p)dp , \quad t > 0 \tag{7}$$

and

$$\frac{u(0+)}{2} = \lim_{R\to\infty} \int_{\gamma-iR}^{\gamma+iR} f(p)dp \tag{8}$$

where $u(0+) = \lim_{\epsilon\to 0} u(0+\epsilon)$, $\epsilon > 0$,

$$f(p) = q(p)/h(p) ,$$

$$q(p) = g(\eta)e^{-\eta p} + p\int_0^\eta g(x)e^{-px}dx$$

and γ is such that $\mathrm{Re}(p_j) < \gamma$ where p_j are the roots of $h(p) = 0$, which for the particular example are countably infinite in number and are distinct.

SILBERSTEIN'S EXAMPLE

Returning to equation (1) we have the transform $U(p)$ of $u(t)$ given by

$$h(p)U(p) = g(0) + \int_0^\eta e^{-px}g'(x)dx . \tag{9}$$

Assuming that $g(x)$ can be differentiated n times in the interval $(0,n)$ we can develop the integral to obtain

$$h(p)U(p) = g(0) + \frac{g'(0) - e^{-\eta p}g'(\eta)}{p} + \frac{g''(0) - e^{-\eta p}g''(\eta)}{p^2} + \ldots .$$

giving

$$\tfrac{1}{2}g(0) = g(0)\sum \frac{1}{1+\eta p_j} + g'(0)\left(\sum \frac{1}{p_j(1+\eta p_j)} - 1\right) - g'(\eta)\left(\sum \frac{1}{1+\eta p_j} - \tfrac{1}{2}\right) + \ldots . \tag{10}$$

since $\lim_{R\to\infty} \frac{1}{2\pi i}\int_{\gamma-iR}^{\gamma+iR} \frac{dp}{p(p-e^{-\eta p})} = \sum \frac{1}{p_j(1+\eta p_j)} - 1$

and $\lim_{R\to\infty} \frac{1}{2\pi i}\int_{\gamma-iR}^{\gamma+iR} \frac{e^{-\eta p}\,dp}{p(p-e^{-\eta p})}$

$= \lim_{R\to\infty} \frac{1}{2\pi i}\int_{\gamma-iR}^{\gamma+iR} \left(\frac{1}{p-e^{-\eta p}} - \frac{1}{p}\right) dp$

$= \sum \frac{1}{1+\eta p_j} - \frac{1}{2}$.

Since $g(x)$ is an arbitrary function, equation (10) can only hold if

$$\sum \frac{1}{1+\eta p_j} = \frac{1}{2} \qquad (11)$$

$$\sum \frac{1}{p_j(1+\eta p_j)} = 1 \ . \qquad (12)$$

It can be seen that the assumption $g'(\eta) = g(0)$ removes the first series (11) and the two difficulties arising at $t = 0$ viz. the fact that the inversion integral equals $\frac{1}{2}u(0+)$ and the integral

$$\lim_{R\to\infty} \frac{1}{2\pi i}\int_{\gamma-iR}^{\gamma+iR} \frac{dp}{p} = \frac{1}{2} \ .$$

A SIMPLE APPROACH

Let us simplify the problem by taking $g(t) = 1$. Then

$$U(p) = \frac{1}{h(p)} \ .$$

On inversion we obtain, using (7) and (8)

$$\left.\begin{aligned} u(t) &= \sum \frac{e^{p_j t}}{1+\eta p_j} \qquad t > 0 \\ \frac{1}{2} &= \sum \frac{1}{1+\eta p_j} \qquad t = 0 \end{aligned}\right\} \qquad (13)$$

whereas from the expansion

$$U(p) = \sum_{r=0}^{\infty} \frac{e^{-r\eta p}}{p^{r+1}}$$

we obtain

$$u(t) = \sum_{r=0}^{\infty} \frac{(t-r\eta)^r}{r!} H(t-r\eta) \ , \quad t > 0 \qquad (14)$$

where $H(t)$ is the Heaviside unit function.

Further from the identity

$$\frac{1}{p^{t/\eta}} = \frac{1}{p^{t/\eta}(1+\eta p)} + \eta \cdot \frac{1}{p^{(t/\eta)-1}(1+\eta p)}$$

it follows using (13) and (14) that

$$\sum \frac{1}{p_j^{t/\eta}} = u(t) + \eta u(t-\eta) \ , \quad t > \eta \qquad (15)$$

$$= 1 + t \sum_{r=1}^{\infty} \frac{(t-r\eta)^{r-1}}{r!} H(t-r\eta) \ .$$

Equation (15) gives the value of the sum of any inverse powers of p_j and in particular with $\eta = 1$, we can show

$$\sum \frac{1}{p_j} = \frac{3}{2} \ , \quad \sum \frac{1}{p_j^2} = 3 \ , \quad \sum \frac{1}{p_j^3} = \frac{11}{2} \ .$$

From (13) and (14), if we take $t = 1,2,3$ we have immediately equations (5), (6) and

$$\sum \frac{1}{p_j^3(1+p_j)} = \frac{7}{2} \quad \text{respectively.}$$

GENERALISATIONS

If we take

$$g(t) = e^{bt} \ , \quad (b \neq p_j \ , \text{ for any } j \ )$$

in equation (1), it is a straight forward matter to obtain the result

$$\sum \frac{1}{p_j - b} = \frac{\eta + (2+\eta b)e^{nb}}{2(1-be^{nb})} \ . \qquad (16)$$

It is now possible to obtain any series $\sum \frac{1}{(p_j-b)^n}$ by repeatedly differentiating both sides of (16) with respect to b . If we take

$$\frac{d}{db}\left[\sum \frac{1}{p_j-b}\right]_{b=-\frac{1}{\eta}} \quad \text{we obtain}$$

$$\sum \frac{1}{(1+\eta p_j)^2} = \frac{1}{1+\eta e} \ . \qquad (17)$$

Further generalisations may be obtained by using the derivative

$$\frac{dp_j}{d\eta} = -\frac{p_j^2}{1+\eta p_j} \ . \qquad (18)$$

Then if we write

$$F_k(\eta) = \sum \frac{1}{(1+\eta p_j)^k} \qquad (19)$$

we obtain the recurrence relation

$$F_{k+2}(\eta) = F_{k+1}(\eta) + \frac{\eta}{k} F_k'(\eta) \qquad (20)$$

with the starting values $F_1(\eta) = \frac{1}{2}$, $F_2(\eta) = \frac{1}{1+\eta e}$ as in equations (11) and (17). It is then immediate from (20) that

$$F_3(\eta) = \frac{1}{1+\eta e} \qquad (21)$$

$$F_4(\eta) = \frac{2+\eta e}{2(1+\eta e)^2} \; . \qquad (22)$$

ACKNOWLEDGMENT

The authors would like to thank J.L. Griffith for his helpful comments on an early draft of this paper.

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(Manuscript received 22.11.1976)

Journal and Proceedings, Royal Society of New South Wales, Vol. 110, pp. 33–40, 1977

Floral Evidence for a Middle Triassic Age of the Gunnee Beds and Gragin Conglomerate, near Delungra, New South Wales

D. J. Bourke, R. E. Gould, R. Helby, R. Morgan and G. J. Retallack

ABSTRACT. The Gunnee Beds, near Delungra, northern New South Wales, are a sequence of arkose, conglomerate, prominent sublabile sandstones, carbonaceous shale, and coal, unconformably overlying Late Palaeozoic rocks of the New England Fold Belt, and overlain by the Gragin Conglomerate with cobbles of quartz-feldspar porphyry and acid volcanics. Megafossil and microfossil floras obtained from the Gunnee Beds and Gragin Conglomerate indicate a Middle Triassic age. These are the only Triassic strata which crop out in the Warialda Trough on the west of the Woolomin-Texas Block of the New England Fold Belt. Deposition and preservation of Middle Triassic terrestrial sediments both east and west of the New England region, indicate that the major unroofing of the New England Batholith had probably been completed by this time.

INTRODUCTION

In 1954, Rade (1954a) reported a Triassic megafossil flora from carbonaceous shales exposed in the bank of Warialda Creek, north-west of Delungra, N.S.W. Five species of the flora were subsequently identified by Dr. A.B. Walkom (in Rade, 1954b) and the containing strata, designated the Gunnee Beds, were correlated with the Ipswich Coal Measures of Queensland on the basis of the identified plant megafossils (Rade, 1954b). This was of interest as the Gunnee Beds were the only known Triassic strata outcropping at the base of the Surat Basin on the north-western margin of the Palaeozoic New England Tablelands region. Rade (1954b) correlated the overlying Gragin Conglomerate with the Bundamba Group of Queensland and considered it to be of Jurassic age. Since then, however, these units have been shown on maps in part as Permian granite and Tertiary sediments by Chesnut and Cameron (1971) and Pogson and Hitchins (1974).

During recent mapping in the area (Bourke, 1974), D.J.B. relocated Rade's site in the Gunnee Beds (Figure 1); this led R.E.G. and G.J.R. to collect further specimens, including palaeopalynological samples, and to re-examine Rade's material housed in the Australian Museum. Palaeopalynological samples were also collected from a shale and siltstone lense in the Gragin Conglomerate, and a collection of plant megafossils from this unit examined. The palaeopalynological samples were investigated by R.M. and R.H.

No attempt has been made here at major taxonomic description, the fossils merely being identified by comparison with known forms. Plant megafossils from the Gunnee Beds are housed in the Australian Museum (prefixed AMF) and the Geology Department, University of New England (prefixed UNEF); those from the Gragin Conglomerate and all figured microfossils in the Geological and Mining Museum of the Geological Survey of New South Wales (prefixed MMF and MMMC). Stage co-ordinates refer to the rotary stage of the Geological and Mining Museum's Zeiss Photomicroscope No. 67500. Unfigured palaeopalynological material is lodged in the palynology collection of the Geological and Mining Museum, catalogue number 2319 (Gunnee Beds), and 2545, 2737, 2738 (Gragin Conglomerate).

STRATIGRAPHY

In the Warialda-Delungra district, Mesozoic sediments nonconformably overlie the New England Fold Belt (Scheibner, 1973; Leitch 1974; Rod, 1975) which in this area consists of highly deformed Palaeozoic cherts, slates, basic volcanics and tuffs (possibly the Woolomin Beds) intruded by granitic rocks of probable Late Carboniferous age. The basal Mesozoic unit of the sequence is the Triassic Gunnee Beds (Rade, 1954b); these may be a marginal equivalent to the Wandoan Formation of the Permo-Triassic Sydney-Bowen Basin. The Gunnee Beds are in turn overlain by the Triassic Gragin Conglomerate. Both the Gragin Conglomerate and the Gunnee Beds are restricted, in outcrop, to a small structural depression east of Warialda, named the Warialda Trough (Bourke, 1974). Sediments of the Surat Basin overlie the Gragin Conglomerate.

In the area shown on Figure 1, the Gunnee Beds consist of coarse-grained to granular sublabile sandstone and arkose, interbedded with medium- to fine-grained labile sandstone and minor siltstone, carbonaceous shale and mudstone, and coal. The fossil plant horizons are interbedded with and overlain by prominent coarse-grained and granular sandstones. The sequence in this area is considered to represent the finer-grained, upper part of the Gunnee Beds. South and west of Figure 1, where the unit is topographically and probably stratigraphically lower than this sequence, the Gunnee Beds are composed of very coarse-grained to granular arkose, poorly-sorted paraconglomerate and coarse- to very coarse-grained sublabile sandstone. The unit ranges in thickness from 2 m to over 30 m.

The Gunnee Beds appear to have been deposited under terrestrial conditions. It is evident from the immaturity of much of the Gunnee Beds that the sediment was transported only a short distance, and in many outcrops the arkose lies directly on the parent granitic rock. Restriction of the Gunnee Beds to the Warialda Trough and the

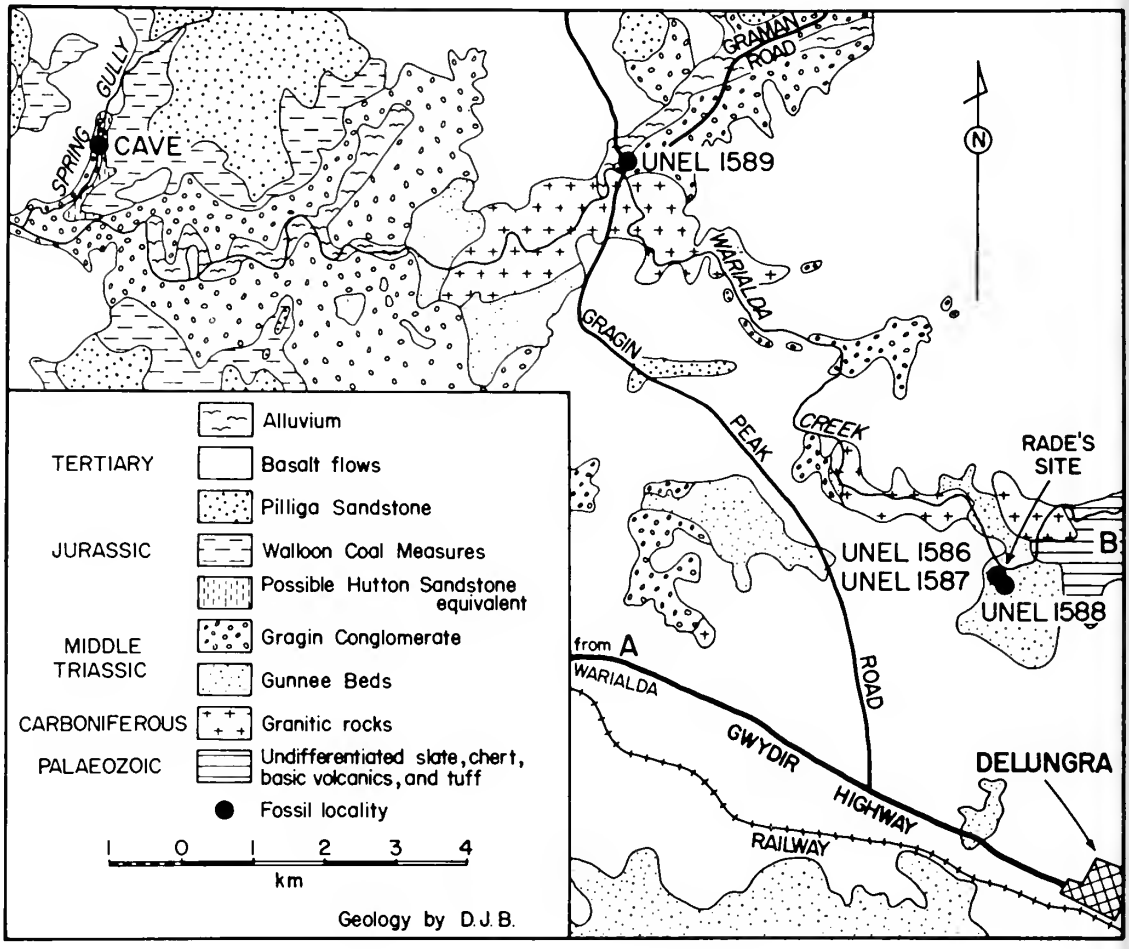


Fig. 1. Geological map of the Delungra area

lithology suggest that the unit may have been deposited in a river valley system with some development of swamps and lakes.

The Gragin Conglomerate is composed dominantly of cobbles (with some pebbles) of quartz-feldspar porphyry and acid volcanics; clasts of granite, chert, and siliceous metamorphosed sediments such as mudstone, sandstone, and pebble conglomerate, are less abundant. The cobbles are about 120 mm in diameter, well-sorted and well-rounded. They are set in a matrix of medium- to coarse-grained sublabile sandstone. There are some lenses of laminar-bedded sublabile sandstone which are infrequently capped by lamellae of siltstone and carbonaceous shale. The conglomerate is exposed as spectacular cliff faces up to 50 m high along Warialda Creek. The Gragin Conglomerate is essentially conformable on the Gunnee Beds but shows an erosive basal contact.

Sediments of the Surat Basin onlap across the Gragin Conglomerate, with the Hutton Sandstone overlying the unit on the western side of the Warialda Trough. Further east towards the margin of the Surat Basin, the Walloon Coal Measures and the Pilliga Sandstone (= Warialda Sandstone of Rade, 1954b) directly overlie the conglomerate. Some erosion of the Surat Basin sediments occurred prior to the area being covered by flood basalts in the Tertiary (Figure 2).

Today the Gunnee Beds and Gragin Conglomerate are exposed in creek banks and other places where they have been exhumed from under the basalt or Surat Basin sediments. The sandstone and the conglomerate of the Gunnee Beds are extensively silicified (a silcrete, cf. Taylor and Smith, 1975) especially where they are overlain by basalt.

MEGAFOSSIL FLORA: GUNNEE BEDS

The flora was collected from three localities (UNEL1586-1588) at GR 883221 on the Bingara

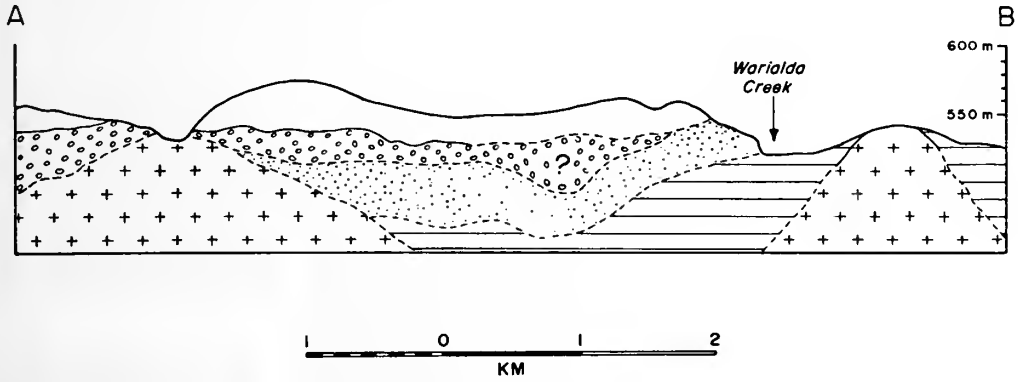


Fig. 2. Geological cross section of the Delungra area.

1:100,000 sheet 9038, approximately 4.75 km NNW of Delungra (Figure 1). The flora is dominated by species of the corystosperm *Dicroidium* and closely related genera typical of the Triassic of Gondwanaland.

Locality UNEL1586 is in a black carbonaceous shale exposed on the southern bank of Warialda Creek. The shale grades upwards into the very fine sandstone and siltstone of UNEL1587. The fossil leaves are commonly oxidised with an oxidation corona developed into the dark matrix, but sometimes carbonised compression material does remain. *Johnstonia coriacea* is the most common of the fossils, which include:

Dicroidium sp. cf. *D. australe* Jacob and Jacob 1950. [AMF45718-9]

D. dubium (Feistmantel) Gothan 1912. [AMF51140]

D. lancifolium (Morris) Gothan 1912. [AMF45735]

D. odontopteroides (Morris) Gothan 1912. [Figure 3.7]

D. zuberi (Szajnocha) Archangelsky 1968; including various small and large fronds. [Figure 3.8]

Dicroidium sp.; like *D. zuberi*, but with pinnules coalescing in the apical part of the pinna and semicircular, wider than long in the basal portion. [AMF51141]

'*Dicroidiopsis*' sp. *sensu* Gould 1967. [Figure 3.12]

Johnstonia coriacea (Johnston) Walkom 1925 *s.s.*; with narrow lamina and entire margins. [Figure 3.5,6]

J. stelzneriana (Geinitz) Frenguelli 1943; includes *D. dentatum* (Walkom) Anderson and Anderson 1970. [Figure 3.10]

Johnstonia sp.; weakly lobed forms intermediate between *J. stelzneriana* and *J. coriacea*, including *Dicroidium* (intermediate sp. A) Anderson and Anderson 1970. [Figure 3.9]

Xylopteris elongata (Carruthers) Frenguelli 1943. [Figure 3.11]

Pteruchus sp. cf. *P. simmondsii* (Shirley) Thomas 1933, *sensu* Townrow 1962; macroscopically intermediate between *P. johnstonii* (Feistmantel) Townrow 1962 and *P. simmondsii*. [UNEF15081-2]

Pilophorosperma sp. cf. *P. burnerense* Thomas 1933. [UNEF15079; UNEF15080 is a similar specimen but about half the size]

Isolated corystosperm seed; similar to that figured by Thomas (1933, fig. 33e) but rather more elongate. [UNEF15083]

Rissikia media (Tenison-Woods) Townrow 1967. [Figure 3.14]

Locality UNEL1587 is in a leached siltstone and very fine sandstone immediately underlying the bluff-forming sandstone and granule conglomerate on the southern bank of Warialda Creek; the locality is about 1 m above UNEL1586. The plant remains, which are all fragmentary and naturally macerated to varying degrees, include:

Cladophlebis lobifolia (Phillips) Seward 1900, *sensu* Walkom 1924. [Figure 3.1]

Cladophlebis sp. cf. *oblonga* Halle 1914; similar specimen illustrated by Frenguelli (1947, pl. 5, fig. 7). [Figure 3.2]

Asterotheca menendezii de la Sota and Archangelsky 1962; probably includes fertile *Cladophlebis australis* of Walkom (1917). [Figure 3.3]

Dicroidium lancifolium (Morris) Gothan 1912; most like '*Thinnfeldia*' *acuta* Walkom 1917. [Figure 3.4]

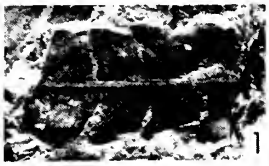
Pteruchus johnstonii (Feistmantel) Townrow 1962. [AMF51132]

Ginkgoites moltenensis (Seward) Du Toit 1927; includes *G. digitata sensu* Walkom 1917. [AMF51142]

Rissikia sp. cf. *R. apiculata* Townrow 1967. [Figure 3.13]

Locality UNEL1588 is a grey shale underlying a thin coal seam in a small north-flowing tributary gully of Warialda Creek, about 70 m southeast of UNEL1586 and UNEL1587. This locality is probably a few metres stratigraphically lower than UNEL1586. Fossils collected:

Dicroidium odontopteroides (Morris) Gothan 1912. [UNEF15084]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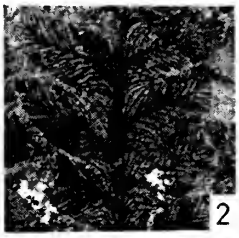
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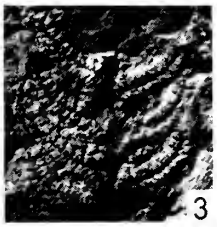
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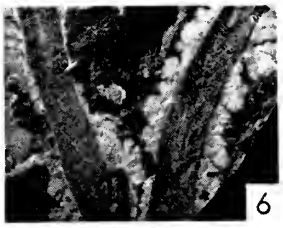
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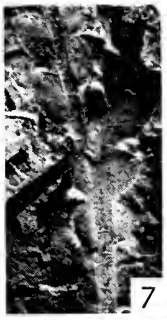
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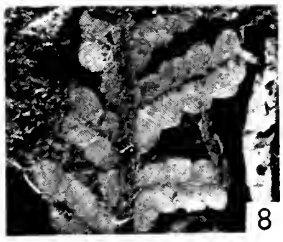
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Pilophorosperma sp. cf. *P. Burnerense* Thomas 1933. [UNEF15085-6]

Many of the forms present, e.g. *D. odontopteroides, D. dubium, J. coriacea, J. stelzneriana, X. elongata,* and *P. johnstonii*, are commonly given Middle to Late Triassic ranges (Stipanicic and Bonetti, 1969; Banks, Cosgriff, and Townrow, 1967; Anderson and Anderson, 1970). However local comparisons suggest a Middle Triassic (Anisian to Ladinian) age for the Gunnee Beds. *Cladophlebis lobifolia sensu* Walkom (1924) is only known from the Middle Triassic Esk and Neara Beds of Queensland and the Middle Triassic Nymboida Coal Measures of New South Wales (Flint and Gould, 1975); a basalt flow in the Nymboida Coal Measures has yielded a Middle Triassic radiometric date of 211 ± 5 x 10^6 years (Retallack, Gould, and Runnegar, in press). *Johnstonia coriacea* (*s.s.* with entire margins) is much more frequent in the Esk Beds than in the Late Triassic Ipswich Coal Measures (Jones and de Jersey, 1947, p. 19; de Jersey, 1972), and also occurs at one horizon in the Basin Creek Formation of the Nymboida Coal Measures (UNEF14718 from UNEL1489). *Xylopteris elongata* is common in the Ipswich Coal Measures, but is also found in the early Middle Triassic Hawkesbury Sandstone at Brookvale, N.S.W. (AMF18581); only one specimen has been found in the Gunnee Beds. The flora from the overlying Gragin Conglomerate is also of Middle Triassic age and so restricts the youngest age assignable to the Gunnee Beds.

This Middle Triassic age determination was independently substantiated by palaeopalynological evidence.

MICROFOSSIL FLORA: GUNNEE BEDS

A palaeopalynological sample from the black carbonaceous shale at the plant megafossil locality UNEL1586 on Warialda Creek, was processed and examined by R.M. and R.H. The microfossil flora is dominated by *Falcisporites australis* (de Jersey) Balme 1970 [Figure 3.18] and includes the following additional important forms:

Aratrisporites parvispinosus sensu Helby 1973. [Figure 3.16, 17]
Aratrisporites tenuispinosus sensu Helby 1973.
Baculatisporites comaumensis (Cookson) Potonié 1956.
Cycadopites follicularis Wilson and Webster 1946. [Figure 3.15]
'Guthoerlisporites' cancellosus Playford and Dettmann 1965.
Indospora clara Bharadwaj 1962.
'Nevesisporites' limatulus Playford 1965.
Polypodiisporites mutabilis Balme 1970.
Protohaploxypinus samoilovichii (Jansonius) Hart 1964.
Protohaploxypinus sp. cf. *P. jacobii* (Jansonius) Hart 1964.
'Retusotriletes' radiatus (Kara-Murza).
Uvaesporites sp. cf. *U. verrucosus* (de Jersey) Helby ex de Jersey 1971.
Verrucosisporites sp. cf. *V. carnarvonensis* de Jersey and Hamilton 1967.

The microflora recovered from the Gunnee Beds exhibits restricted diversity, but the mutual occurrence of *A. parvispinosus, P. samoilovichii, U.* sp. cf. *U. verrucosus*, and *V.* sp. cf. *V. carnarvonensis* suggest a close comparison with the *A. parvispinosus* Assemblage Zone of Helby (1973) which is of Middle Triassic age. The apparent absence of *Annulispora* spp. and *Craterisporites rotundus* de Jersey 1970 from the Gunnee Beds association may differentiate it from the *C. rotundus* Zone which characterises the Late Triassic Ipswich Coal Measures (de Jersey, 1975). This is substantiated by the occurrence in the Gunnee Beds of *P.* sp. cf. *P. jacobii* and *V.* sp. cf. *V. carnarvonensis* which do not appear to range into strata younger than mid-Ladinian (R.H.). An Anisian/Ladinian age is thus suggested.

Helby (1973) indicated that the *A. parvispinosus* Assemblage Zone also occurred in the Wandoan Formation, the Clematis Sandstone and the Moolayember Formation in the Bowen Basin of Queensland. Although the Gunnee Beds microfossil flora is clearly similar to the assemblages reported from the Wandoan Formation (de Jersey and Hamilton, 1969), the Clematis Sandstone (de Jersey, 1968), and the Moolayember Formation (de Jersey and Hamilton, 1967), none of the species regarded as diagnostic of the *Duplexisporites problematicus* Microflora by de Jersey (1975) were encountered. The apparent absence of these species and the restricted diversity of the Gunnee Beds assemblage may possibly be explained by the extreme proximal position of the Gunnee Beds in the Wandoan/Moolayember drainage system.

Fig. 3. 1, *Cladophlebis lobifolia* (Phillips) Seward *sensu* Walkom; portion of pinna showing characteristic pinnules. AMF51128, X 1.5. 2, *Cladophlebis* sp. cf. *C. oblonga* Halle. AMF51129, X 1.8. 3, Portion of fertile pinna of *Asterotheca menendezii* de la Sota and Archangelsky. AMF51130, X 1.5. 4, *Dicroidium lancifolium* (Morris) Gothan. AMF 51131, X 1.5. 5, 6, *Johnstonia coriacea* (Johnston) Walkom *s.s.* 5, AMF51133, X 0.9. 6, AMF51134, X 1. 7, *Dicroidium odontopteroides* (Morris) Gothan. AMF51135, X 1.1. 8, *Dicroidium zuberi* (Szajnocha) Archangelsky. AMF51136, X 0.75. 9, *Johnstonia* sp. AMF51137, X 0.6. 10, *Johnstonia stelzneriana* (Geinitz) Frenguelli. AMF51138, X 1. 11, *Xylopteris elongata* (Carruthers) Frenguelli. AMF45745, X 1.35. 12, *'Dicroidiopsis'* sp. *sensu* Gould. AMF45710, X 0.8. 13, *Rissikia* sp. cf. *R. apiculata* Townrow. AMF51143, X 1.3. 14, *Rissikia media* (Tenison-Woods) Townrow. AMF45693, X 1.6. 15, *Cycadopites follicularis* Wilson and Webster. MMMC2010, 028/0886, X 800. 16, 17, *Aratrisporites parvispinosus* Leschik *sensu* Helby. 16, distal focus. 17, proximal focus. MMMC2011, 042/1102, X 800. 18, *Falcisporites australis* (de Jersey) Balme. MMMC2011, 050/1070, X 800.

MEGAFOSSIL FLORA: GRAGIN CONGLOMERATE

A collection of plant megafossils was obtained by D. Probert from small, khaki shale and siltstone lenses interbedded with the conglomerate at UNEL1589. The locality is in a gravel pit near the junction of the Graman and Gragin Peak Roads at GR 831281 on the Bingara 1:100,000 sheet 9038. Determinations include:

Dicroidium sp. cf. *D. eskense* (Walkom) Jacob and Jacob 1950; poorly preserved, with some transverse creasing of the pinnae. [MMF 17080, MMF17084]

D. odontopteroides (Morris) Gothan 1912. [MMF 17085-6]

D. zuberi (Szajnocha) Archangelsky 1968; small fronds like the one figured from the Gunnee Beds. [MMF17081-3]

Lepidopteris madagascariensis Carpentier 1935. [MMF17090]

Presence of *Dicroidium* spp. indicates a Triassic age for the flora. *Lepidopteris madagascariensis* ranges from Early to Middle Triassic (Townrow, 1966) while *D. odontopteroides* ranges from Middle to Late Triassic (Townrow, 1967), so a Middle Triassic age for the Gragin Conglomerate is most likely. This is substantiated by the presence of a frond comparable to *D. eskense* which is restricted to Middle Triassic floras of eastern Australia (see Flint and Gould, 1975).

MICROFOSSIL FLORA: GRAGIN CONGLOMERATE

Several samples collected from siltstone and carbonaceous shale horizons at the top of a small sandstone lense of the Gragin Conglomerate in a cave on the eastern bank of Spring Gully (Bingara 1:100,000 sheet 9038, GR 759284) were subjected to palaeopalynological investigation. Spores and pollen recovered from the Gragin Conglomerate samples were even more restricted than those from the Gunnee Beds. Palynomorphs identified include:

Converrucosisporites cameronii (de Jersey) Playford and Dettmann 1965.

Cycadopites follicularis Wilson and Webster 1946.

Dictyophyllidites mortonii (de Jersey) Playford and Dettmann 1965.

Falcisporites spp., including *F. australis* (de Jersey) Balme 1970.

Guttatisporites visscheri de Jersey 1968.

Necraistrickia taylori Playford and Dettmann 1965.

Osmundacidites wellmanii Couper 1953.

Polypodiisporites ipsviciensis (de Jersey) Playford and Dettmann 1965.

Punctatisporites spp.

Punctatosporites walkomii de Jersey 1962.

Rugulatisporites sp.

Tuberculatosporites spp.

Uvaesporites sp. cf. *U. verrucatus* (de Jersey) Helby ex de Jersey 1971.

Vitreisporites pallidus (Reissinger) Nilsson 1958.

Circulisporites parvus (de Jersey) Norris 1965 - acritarch.

Falcisporites and *Polypodiisporites* were the most prominent genera in the samples. The microfossil association is clearly Triassic in age but the apparent absence of diagnostic species (discussed above in relation to the Gunnee Beds microfossil flora) precludes more definitive age assignment beyond suggesting that they are no older than Middle Triassic.

DISCUSSION

The Middle Triassic age assigned to the Gunnee Beds and Gragin Conglomerate is thus based on both plant megafossil and microfossil data. Fossil plant-bearing sediments of a similar age occur to the north in the Bowen Basin (de Jersey and Hamilton, 1967, 1969) and the Esk Trough of southern Queensland (de Jersey, 1972; Figure 4), to the east at Nymboida in the southern Clarence-Moreton Basin (Flint and Gould, 1975), far to the south in the Sydney Basin (Helby, 1973), and possibly to the south-west in the Gunnedah Basin as well (Hind and Helby, 1969; Bembrick, Herbert, Scheibner, and Stunz, 1973).

The Delungra and Nymboida Middle Triassic sediments impose some constraints on interpretations of the New England region. The granitic rocks of the New England Batholith which intrude the Palaeozoic basement have been assigned Late Carboniferous to Early Triassic radiometric ages (Wilkinson, 1974), and the deposition and preservation of Middle Triassic coal measures on erosion surfaces of this complex probably means that most of the unroofing of the New England Batholith was completed by the Middle Triassic. The Gunnee Beds near Delungra have been deposited on granitic rocks of the batholith and contain much quartzose and arkosic sediment. The clasts of the overlying Gragin Conglomerate are mostly of quartz-feldspar porphyry with some granitic rocks. The Nymboida Coal Measures, unconformably overlying the Late? Palaeozoic sediments of the Coffs Harbour Beds (Korsch, 1971), contain the Bardool Conglomerate (McElroy, 1963). The majority of clasts in the Bardool Conglomerate are rhyolitic and/or ignimbritic; clasts of greywacke, siltstone, and chert from the underlying Palaeozoic sediments are also present. So it seems the source for much of the sediment in these Middle Triassic units was from erosion of the granitic rocks of New England and their volcanic and sub-volcanic equivalents. The granitic rocks underlying the Gunnee Beds are probably among the earliest intrusives of the batholith, but even so they had already been exposed and eroded by the Middle Triassic. The later intrusives of the batholith show characters of high level emplacement (Wilkinson, 1974) which is not inconsistent with a relatively rapid erosion of the intruded country rocks.

ACKNOWLEDGEMENTS

D.J.B. and R.M. publish with the permission of the Under Secretary, New South Wales Department of Mines. Dr J. Pickett drew our attention to the collection of fossils from the Gragin Conglomerate. Mr H. Butler and Mr K. Williams assisted in collection of plant fossils and provided valuable discussion. Dr A. Ritchie and Miss D. Jones kindly provided access to material in the Australian Museum. The maps were drafted by Mr M. Bone.

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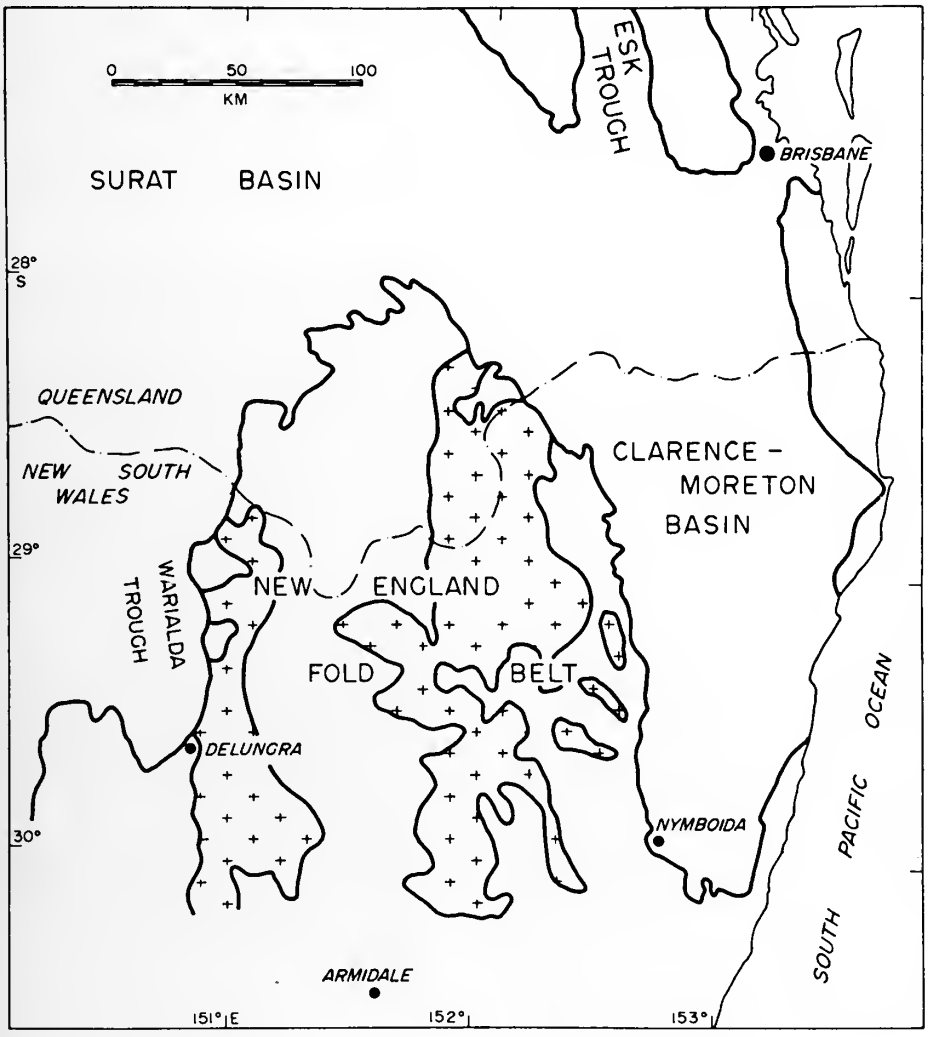

Fig. 4. Location map.

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(Manuscript received 3.4.1975)
(Manuscript received in final form 10.8.1976)

Journal and Proceedings, Royal Society of New South Wales, Vol. 110, pp. 41–47, 1977

The Tertiary Stratigraphic Palynology of the Murray Basin in New South Wales. 1. The Hay-Balranald-Wakool Districts

HELENE A. MARTIN

ABSTRACT. The Hay, Balranald and Wakool districts are situated on entirely non-marine sediments, to the east of the limit of marine transgression of the Murray Basin. This palynological study of ten selected bores relates the sediments to the geological time scale by correlating the assemblages with the spore-pollen zones described for the Gippsland Basin. In this part of New South Wales, the deepest and oldest sediments, below 305m, are middle Eocene in age. Late Eocene assemblages are found below about 274m. Oligocene - early Miocene sediments form thick sections between approximate levels of 120m and 270m, and are encountered in every bore. Carbonaceous clays and lignites are common and the climate during deposition of these sediments must have been very humid, with lakes and swamps a feature of the landscape. Middle Miocene and younger assemblages have been recovered from only four of the bores examined. During deposition of the upper 100m, it appears that conditions were not favourable for pollen preservation. About the middle Miocene, the deposition of carbonaceous clays and lignites ceased and the rainfall must have decreased, although the continuance of the grey colour of the clays indicates that it was uniformly distributed through the year, with no marked dry season.

INTRODUCTION

The Murray Basin, over 259,000 square km. in area, extends into South Australia, Victoria and New South Wales. Tertiary sediments comprise the main bulk of the basin deposits, with a maximum thickness of some 500m in the central part, thinning out towards the basin margins. They have a complex stratigraphy which has been the subject of numerous reports (e.g. Ludbrook, 1961; Pels, 1960, 1969; Lawrence, 1966; Bembrick, 1974). These studies, however, have all been restricted to particular areas and there remain large parts of the basin that have been little investigated. Sediments in the eastern part of the basin are entirely non-marine and palynology is the only method readily available to relate them to the geological time scale. This paper presents the stratigraphic palynology from bores of the Hay, Balranald and Wakool districts in the east-central part of the basin, (see Fig. 1).

There is one report of a palynological study in this area, that of Evans and Hodgson (1963). Material from bores of this study have been re-examined in the light of the considerable advances made since these authors completed their report.

GEOLOGY

Of major significance to the Tertiary stratigraphy of the Basin is the eastern limits of the marine transgressions which extends from the west. Pels (1960) suggest that a probable basement ridge with a north easterly orientation, between the Lachlan and lower Darling Rivers, marks the limit of marine deposition. There is a dolomite bed at approximately 121-152m in the Balranald No. 1 Bore, (see Fig. 1), but this is the only evidence of marine deposition in the area of this study. While not providing any additional information on the location of the limit of the marine transgression, present results are not inconsistent with Pel's proposal.

A number of units have been described by previous authors, but only two have relevance to this non-marine area, the Renmark Beds (formerly the Knight Group, Harris, 1966b), and the Wunghnu Group (Lawrence, 1966).

The Renmark Beds are the most widespread of the units, and form the base of the Tertiary sequence. They consist of fine to medium-grained quartz sand; silt and siltstone which may be carbonaceous, dolomitic or calcareous; clay, usually carbonaceous, and lignites. The various sediments form alternating strate which inter-tongue. Evidence from elsewhere in the basin only indicates a Lower Tertiary age (Ludbrook, 1963; Lawrence, 1966). Bembrick (1974) distinguishes the upper and lower Renmark Beds: the former are dominantly sandy with minor shale, siltstone and lignitic lenses whereas the latter are more argillaceous and carbonaceous. Because the Renmark Beds are overlain by several different younger units elsewhere in the basin, their upper boundary may not be synchronous.

The Wunghnu Group (described from the Northern Plains of Victoria) overlies the Renmark Beds, beyond the limits of the marine transgressions. The sediments are fluviatile and lacustrine, highly variable in lighology, mottled throughout and contain numerous paleosols. The criterion used to discern the boundary between the Wunghnu Group and the Renmark Beds is the shallowest occurrence of the persistent carbonaceous beds which are characteristic of the latter (Lawrence, 1966). The upper surface of the unit is defined as the present land surface.

Selected bore logs are presented in Fig. 3.

Five of the bores reached basement but the five most northerly ones were terminated before basement was reached. The logs show that the sediments are fine-grained and consist mainly of clay and silt with relatively minor amounts of sand. The latter are usually fine-grained with a particle size of about 2-2½mm or less. The clay colour is red-yellow-brown, as well as grey, down to about 90m, below which only various shades of grey are found. This boundary can be observed in every bore. Near Hay, it may be shallower, up to 67m, whereas further south, it is deeper, down to 109-112m. The grey colour found alternating with the various shades of red-yellow-brown in the upper 90m is invariably pale, and carbonaceous material has not been found here. Carbonaceous clays first occur below about 90m, where the red-yellow-brown coloured clays are entirely absent. Near Hay, the boundary appears to be shallower, but it is a layer of light grey above the carbonaceous clays which accounts for this apparent shallowness. If the previously described units are extended to this area, then the Wunghnu Group would extend down to about 90m (although mottling is not apparent in the bores described here), and the Renmark Beds below.

In the sediments of the Lachlan River Valley, Williamson (1964) has described two units; the upper one highly variable but mainly red-brown in colour (Cowra Formation) and the lower one grey in colour (Lachlan Formation). This division is based on the dominant rock type of the sand and gravels. In the upper unit it is a mixture of the various country rocks of the catchment area whereas in the lower, it is almost entirely quartz. In the sediments of this study, gravels are rarely encountered, and the sands, where they occur, are usually described as quartz so a division based on rock type is not possible. It seems probable, however, that the Cowra and Lachlan Formation together are the lateral equivalent of at least the upper part of the Wunghnu Group, and possibly the whole group.

THE SPORE-POLLEN ZONATION

Appendix 1 gives full title and Fig. 1 shows the location of bores selected for presentation in this paper. A number of other bores have been examined, but they repeat the evidence of those selected and presented here. Samples from these bores were treated as described in Martin, (1973a).

The assemblages presented in Appendix 2* have been correlated with the spore-pollen zones described by Stover and Patridge (1973) for the Gippsland Basin. These authors have assigned a time range to the zones from evidence of the foraminiferal assemblages in the interbedded marine strata. Fig. 2 presents the time ranges of the spore-pollen zones. By adopting this approach, it is assumed that similar events were synchronous in the Gippsland and Murray Basins, unless there is evidence to the contrary. For assemblages which are younger than those described by Stover and Partridge (1973) the tentative scheme of Martin (1973b) has been followed.

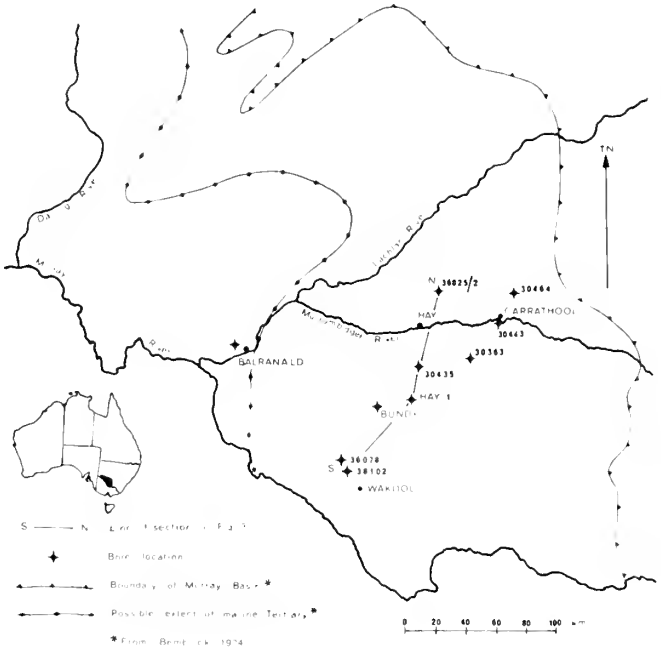

Fig. 1. Locality Map.

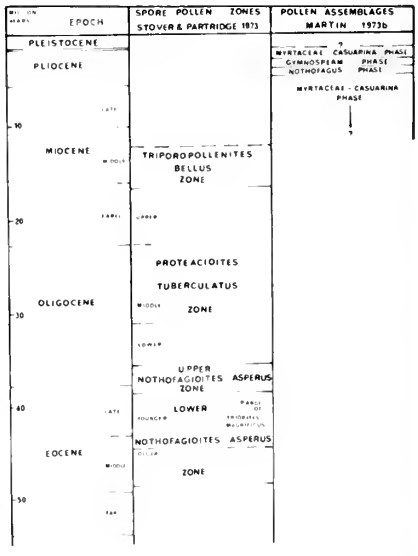

Fig. 2. Time ranges of the palynological zones, from Stover and Partridge, 1973 and Martin 1973b.

*Appendix 2 is available from the author, on request.

In general, these assemblages fit the spore-pollen zones quite well. Occasionally some of the evidence appears contradictory, but when all of the evidence is examined, it is usually overwhelmingly in favour of one particular spore-pollen zone. The time ranges given by Stover and Partridge for some of the species have proven unreliable, but these have not been used in the determination of the spore-pollen zones. In many cases, there is a continuous gradation from one zone to another.

1. The Lower *Nothofagidites asperus* zone (for time ranges see Fig. 2) is the oldest of the Tertiary zones found anywhere in these studies. Two subdivisions have been recognised; an older or pre-*Triorites magnificus* and a younger, containing *T. magnificus*. The older subdivision contains a wealth of the distinctive species which terminate their range by the end of the Lower *Nothofagidites asperus* zone, and *Proteacidites* spp. are abundant. *Nothofagidites* spp. far outnumber *Haloragacidites harrisii*, and this shows that these assemblages cannot be any older than the Lower *Nothofagidites asperus* zone. The younger subdivision of this zone contains fewer of these distinctive species, but *Triorites magnificus* is present.

Distribution: the older subdivision, Hay 1 at 317m and 329m and Bundy at 385-386m. The younger subdivision, Wakool 36078 at 280-333m and Wakool 36102 at 285-311m. Based on the number of distinctive species for the zone, these assemblages form a series with Bundy the oldest, Hay 1 intermediate and Wakool the youngest. A.D. Partridge (pers. comm.) considers that the Hay 1 assemblage may belong to the younger subdivision, but its relative position in the series is correct.

2. The Upper *Nothofagidites asperus* zone has a restricted diversity and Stover and Partridge (1973) consider that it is transitional between the Lower *N. asperus* and *Proteacidites tuberculatus* zones. The one occurrence of the Upper *N. asperus* zone in this study has *Proteacidites stipplatus* as the dominant of the *Proteacidites* spp. Curiously, Wakool 36078 has both the Lower *N. asperus* and *P. tuberculatus* zones which simply intergrade without any indication of an assemblage of the Upper *N. asperus* zone.

Distribution: Hay 1 at 283m.

3. The *Proteacidites tuberculatus* zone has been subdivided into three subdivisions, but the indicator species on which this is based are not often encountered in this study, so subdivision is not reliable. The best indicator for the base of the zone, *Cyatheacidites annulatus* is not common in this study, so the base has been delimited on the general characteristics of the assemblages. There is a gradation from the Lower *N. asperus* zone as its characteristic species drop out, one by one, in those bores with close sampling. In common with the older zones, the content of *Nothofagidites* spp. pollen is high and *Myrtaceidites* spp. low. However, near the top of the zone, the relative frequencees change, with a decrease in *Nothofagidites* spp. and an increase in *Myrtaceidites* spp.

Distribution: (1) Bores which reached basement: Hay 1 at 122-210m: Balranald at 186m and 287-288m: Bundy at 207-213m and 277-278m: Wakool 36078 at 126-267m. (2) Bores which did not reach basement ended in the *P. tuberculatus* zone: 30435 at 110-198m: 30383 at 111-178m: 30443 at 102-207m: 30464 at 97-140m: 36025/2 at ?113-139m.

4. The *Triporopollenites bellus* zone has a number of indicator species which are all uncommon to rare in this study. The relative content of *Nothofagidites* spp. is much lower and *Myrtaceidites* spp. much higher than in the *P. tuberculatus* zone, respectively. These two factors make it difficult to draw a line between the two zones. The assemblages of the *P. tubercalatus* - *T. bellus* 'interzone' are quite distinctive in that they have a wealth of angiosperm pollen, especially the tricolpate - tricolporate types, many of which have not been described. Many of these pollen types are present in older assemblages but it is their association that is so distinctive in the *P. tuberculatus* - *T. bellus* 'interzone'.

All of the *T. bellus* assemblages belong to the older part of the zone because *Haloragacidites haloragoides*, which first appears during this zone, has not been found.

Distribution: Wakool 36078 at 94-108m and Hay 36025/2 at 105-?111m.

5. Assemblages younger than the *T. bellus* zone are rarely encountered. Samples above this zone are usually barren or contain a restricted assemblage in such a poor state of preservation that it is unworkable. There are two exceptions, one of the Myrtaceae-*Casuarina* phase (probably the older) and one of the Pleistocene-Recent.

In both these assemblages, Myrtaceae type pollen is the dominant group with *Nothofagidites* either in very low percentages or absent, respectively. The Pleistocene-Recent assemblage has a higher content of *Tubulifloridites* spp. and *Graminidites media*, and together with *Tubulifloridites* spp. and *Graminidites media*, and together with *Tubulifloridites pleistocenicus*, these features are seen only in the Cowra Formation (Martin, 1969).

Distribution: 'Myrtaceae-*Casuarina* phase' in Wakool 36102 at 76-78m: Pleistocene-Recent in Wakool 36078 at 17-18m.

DISCUSSION

Fig. 3 presents the correlation of the stratigraphic columns. The oldest assemblages of this study belong to the Lower *Nothofagidites asperus* zone and are middle Eocene in age. They are found in the deepest sediments, below 305m, in two adjacent bores, Hay 1 and Bundy. Slightly younger assemblages, of about late Eocene age are found to the south in Wakool 36078 and 36102, below 274m. It is possible that these Eocene sediments extend further north, beneath the bores which did not reach basement.

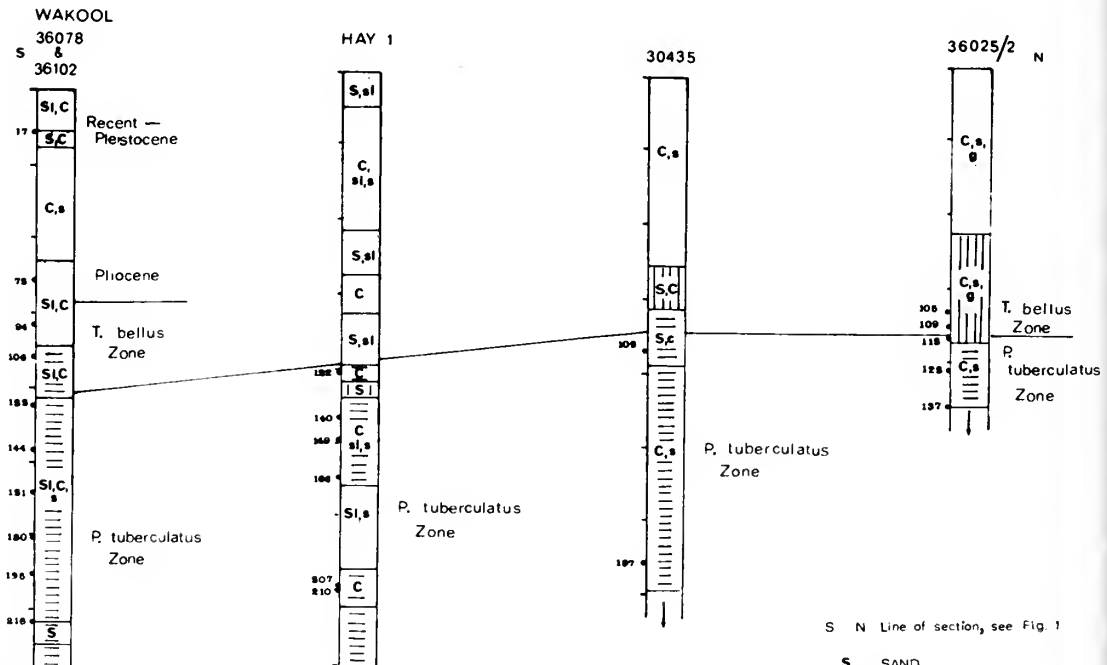

Fig. 3. Correlation of the palynological zones of selected bores. For location of bores, see Fig. 1.

There is a single occurrence of the Upper *Nothofagidites asperus* zone in Hay 1. Where both Lower *N. asperus* and *Proteacidites tuberculatus* zones occur in Wakool 36078 and 36102, there is a complete gradation between the two without any indication of the intermediate Upper *N. asperus* zone. This suggests that assemblages of the Upper *N. asperus* zone may have been produced by certain conditions of the environment and/or deposition.

The *Proteacidites tuberculatus* zone forms the thickest interval in every bore, between the approximate levels of 120m and 270m. Carbonaceous clays and lignites are common, and in some bores deposition of polleniferous sediments has been almost continuous. Both the sediments and pollen assemblages testify to widespread swamps and/or lakes. The top of this zone approximates the upper limit of the carbonaceous clays and is about middle Miocene in age. Using the criterion of Lawrence (1966), this is the top of the Renmark Beds, which here have an age much younger than reported elsewhere (Bembrick, 1974).

Many samples above the carboniferous clays have been examined but most have either yielded no pollen or have such a restricted assemblage with pollen so poorly preserved that it has been unworkable. The two occurrences of the *T. bellus* zone follow closely above the carbonaceous clays. The one Pliocene assemblage of the Myrtaceae-*Casuarina* phase and the one Pleistocene-Recent assemblage both occur in the Wakool bores and probably represent a local lake or billabong.

The age indicated is consistent with the postulated time equivalent to the Wunghnu Group and the Cowra/Lachlan Formation. Today, the area around Wakool is low-lying and subject to inundation at times of higher river levels.

Pels (1969) has described the Tertiary deposition in the Murray Basin in New South Wales and this study allows timing of some of the events. Deposition first started about the middle Eocene. The thick sections of carbonaceous clays and lignites, often containing fossil wood, were formed throughout the Oligocene and early Miocene, although some of the lignites may have started somewhat earlier. Pels describes the upper limits of the carbonaceous clays thus: "..... the upper limits of the lacustrine sediments form horizontal planes bounded by rock. The final lacustrine landscape was therefore one of a series of flat plains bounded by rock outcrops and stepping down to the west and southwest. This former landscape, including its rock outcrops is now buried to an average depth of 90m by ..... fluviatile sediments ....." This ancient lacustrine landscape is middle Miocene in age and the overlying fluviatile sediments include late Miocene, Pliocene and Pleistocene deposition.

The following climatic history can be reconstructed from the evidence of pollen assemblages and the nature of the sediments. There was a long period of a very humid climate throughout the Oligocene and early Miocene, when the rainfall was at least 180cm p.a., and it could have been very much more, judging from present day requirements of *Nothofagus* (Martin, 1969). By middle Miocene time the climate had become less humid, carbonaceous clays were no longer being formed and the abundance of plant types requiring high humidity, e.g. *Nothofagus*, had decreased. The rainfall at this time was probably 150-180cm p.a., fairly uniformly distributed through the year, without a marked dry season (Martin, 1969, 1973b). Conditions had become less suitable for pollen preservation which was restricted to a few localised lakes or billabongs, probably associated with the prevailing river systems. This decrease in humidity occurred in the Murray Basin at an earlier time than in the Gippsland Basin. Stover and Partridge (1973) state: "Specimens of *Nothofagidites* spp. are still abundant in the lower part of the *(T. bellus)* zone, and become gradually less common ..... towards the top." (In contrast, the abundance of *Nothofagidites* spp. has been greatly reduced by the beginning of the *T. bellus* zone in the Murray Basin.) It is to be expected that decreasing humidity will become apparent in inland, continental districts, such as Western New South Wales, before its effects are seen in coastal locations like those of the Gippsland Basin.

ACKNOWLEDGEMENTS

I am indebted to the Water Conservation and Irrigation Commission of New South Wales for the financial assistance without which this work would not have been possible. Messrs. W.H. Williamson and D. Woolley of the Commission have provided invaluable assistance throughout.

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(Manuscript received 20.10.1976)

APPENDIX 1

FULL TITLE AND LOCATION OF BORES

The text uses abbreviated titles in referring to the bores. The full titles are given below:

Balranald: Woodside (Lakes Entrance) Oil and Planet Oil Balranald No. 1 Well, 11 km W. of Balranald.

Bundy: Woodside (Lakes Entrance) Oil and Planet Oil Bundy No. 1 Well, 65 km SSW. of Hay.

Hay I: N.S.W. Oil and Gas N.L. Stratigraphic Test Bore No. 1, 48 km S. of Hay.

Bores sunk by the Water Conservation and Irrigation Commission of New South Wales:

36025/2, 27 km ENE. of Hay

30464, 16 km N. of Carrathool

30383, 43 km SE. of Hay

30443, 1.6 km S. of Carrathool

30435, 26 km S. of Hay

Wakool 36078, 19 km NW. of Wakool

Wakool 36102, 10 km NW. of Wakool.

Journal and Proceedings, Royal Society of New South Wales, Vol. 110, pp. 49-59, 1977.

Leather—Why Is It So?*

EDRIC CHAFFER

ABSTRACT. The fibre structure of hide, skin and leather is developed as one of the earliest fibre sciences, the fundamentals involved in its modification, and also that of its major protein constituent - Collagen - are highlighted, together with a brief outline of some processing involved in leather manufacture. Some of the important properties of leather affecting its everyday application and comfort are also elucidated.

INTRODUCTION

The founding fathers of the Royal Society of New South Wales, stipulated in the aims of our Society, that we are to "encourage studies in Science, Art, Literature and Philosophy, to promote and further the development of Science and allied disciplines and their applications." This presidential address takes the form of a review and proposes to develop these objectives and to highlight their application within our everyday affairs.

For although we are all fully aware that skin forms the outer covering layers of our own bodies, I would venture to suggest that few of us have given consideration to what its basic properties and functions are; or to how we use the skins of animals, converted as leather, for such everyday applications as clothing or footwear, or even for such a small but important usage as a metering cup washer within the carburettor of our motor vehicle.

This address is on the fundamentals which are of importance in understanding about leather, and to be able to do so, it is necessary to fully understand the very important role which the original fibrous structure of animal skin continues to have on the final properties of leather.

The major fibrous protein constituent of hide and skin is the protein collagen and to produce leather it is necessary to remove the other non-collagenous components, and at the same time to physically and chemically modify the remaining network of collagen fibres.

Leather is considered to have been made when the pelt has been stabilized against breakdown by micro-organisms such as bacteria, fungi or enzymes. It is also resistant to the reversing action of water and generally is also accompanied by an increased resistance towards chemical and thermal degradation of protein.

To obtain the above objectives it is very clear that it is necessary to control the physical characteristics of collagen fibres by chemical means - and in doing this the tanner became the very first fibre scientist, for today the leather industry is recognized as the oldest of the many fibre industries.

*Presidential address delivered to the Royal Society of New South Wales at Science House, Gloucester Street, Sydney, on April 7, 1976.

STRUCTURE OF THE SKIN

Living skin is essentially composed of two distinct parts : -

1. The fibrous part.
2. The functional living organisms such as:

   the epidermis, the growing hairs, muscles for the hairs, the fat glands, sweat glands and connective tissue cells. In between the fibres and cells is the lymph containing soluble proteins. (Fig. 1 and Fig. 4)

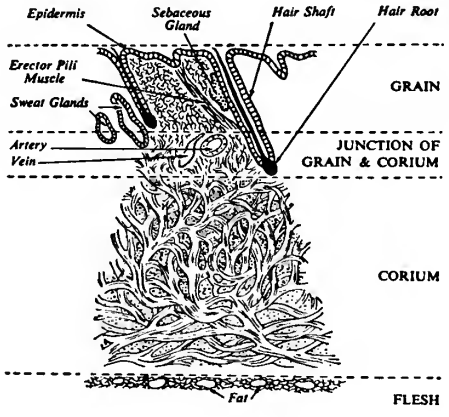


Fig. 1. Diagram to show the general structure of ox hide. (After Sharphouse,1971)

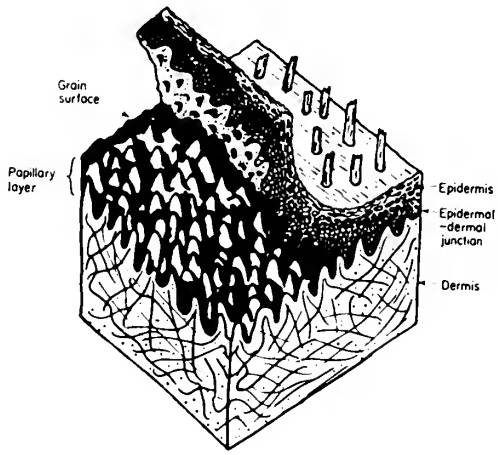


Fig. 2. Diagram of block of skin showing epidermis, epidermal-dermal junction and dermis. A portion of epidermis is peeled off to show papillae in the grain. (After Reed 1976)

It is the fibrous part of the skin only which is of interest to the tanner, for the cellular structures such as the epidermis (Fig. 2) and soluble proteins such as albumins, globulins and mucoids are removed before tanning proper begins. This is generally done with solutions of hydrated lime and a reducing agent such as sodium sulphide, the residue remaining being removed in a bath by using tryptic enzymes. These enzymes attack the hair muscles (erector pili muscle)(Fig. 3) but not the collagen fibres as these are resistant to most enzymes except collagenase.

The fibrous part of the skin is composed mainly of collagen fibres occurring as fibre bundles being generally larger in the corium and smaller in the grain layer.

In a sheath surrounding the collagen fibres is to be found the so-called "reticular tissue". This is currently understood to be a stage in the formation of collagen, known as pro-collagen, but having differing chemical properties. The amino acid composition is similar to that of collagen, but it contains less proline and hydroxyproline and has a greater molecular weight.

Also present in the skin structure are elastin fibres. These occur particularly in the grain layer and in the flesh layers.

The amount and condition of elastin present is of considerable importance to the properties of leather as collagen and elastin differ in their response to swelling agents. In the course of pretanning processes the collagen swells more than the elastin so that the elastin is under stress. Thus, unless the elastin is digested or ruptured it will restrain the even plumping and opening up of the skin, increasing the contrast between areas of the skin where it is present and those where it is relatively absent causing drawn and pebbled grain. It is one of the arts of the tanner to modify and minimize the effects produced by these elastin fibres.

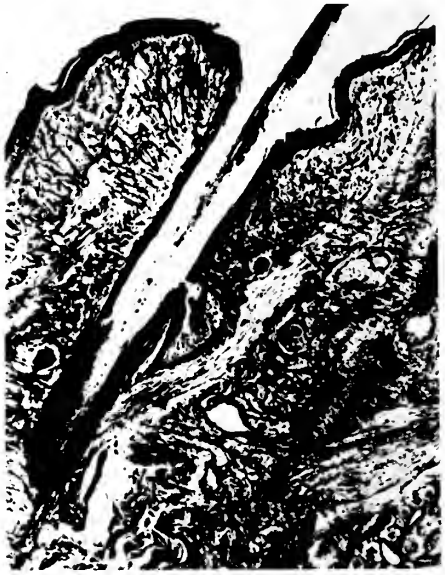


Fig. 3. Vertical section grain showing epidermis erector pili muscle and sebaceous gland. (after Wilson, 1928)

The involuntary hair muscle known as the erector pili muscle is also important (Fig. 3). In life it is affected by shock and cold which causes the hair to stand upright and also gives rise to "goose pimples". This ability of the erector pili muscle to contract still remains after death and can in cold conditions give rise to a coarseness of the grain surface of the hide which would be permanently fixed in leather by tannage. To overcome this defect partial digestion of the erector pilli muscle by bating is carried out with tryptic enzymes. Bating also removes other unwanted proteins and helps to modify reactive sites on the long molecular polypeptide chains of amino acids which go to make up the collagen fibrils, for it is on these reactive sites that the tannin molecules combine.

Each individual hair or wool fibre is contained within its own individual hair follicle with its own fat gland (sebaceous gland). This is important in sheepskins, particularly when they come from animals bred to give much greater yields of fine wool fibres, for under these conditions the skin has developed a layer of fat glands just under the grain layer leaving little room for the cross connecting fibres to connect the grain and the corium. This can result after the removal of the fat in a two layer effect in the skin and also a very open texture (Fig. 6). This defect will lead to greater softness and can make these particular types of skins suitable for clothing leather or oil tanned "chamois" leathers although unsuitable for many other uses.

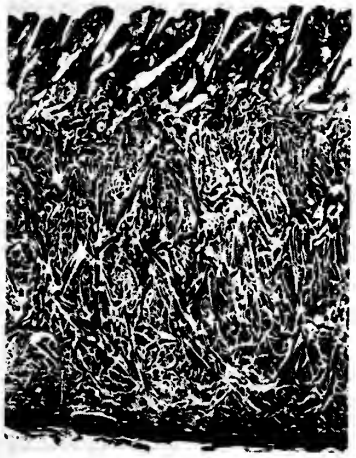


Fig. 4. Vertical section of cow hide x 16
(After Wilson, 1928)

Fig. 5. Vertical section of goatskin x 50
(After Wilson, 1928)

Fig. 6. Vertical section of sheepskin x 50
(After Wilson, 1928)

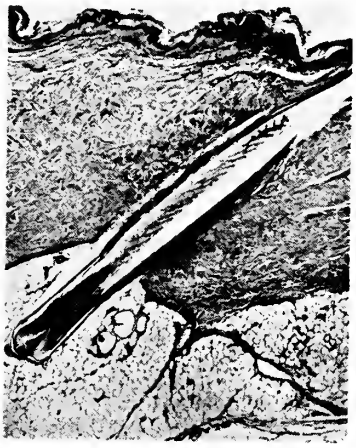


Fig. 7. Vertical section of pigskin x 20
(After Wilson, 1928)

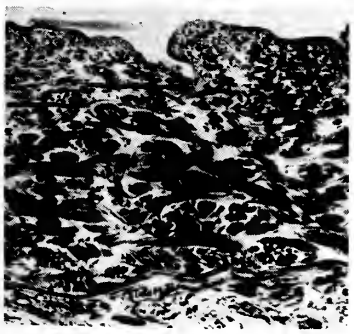


Fig. 8. Vertical section of kangaroo skin x 150

Fig. 9a. Vertical section of snakeskin x 10.8
(After Grassman, 1944)

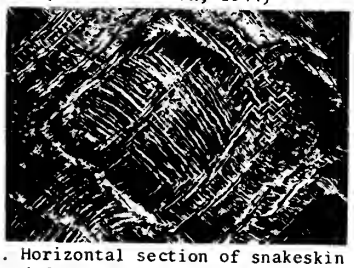


Fig. 9b. Horizontal section of snakeskin x 10.8
(After Grassman, 1944)

As a generalization for sheepskins we could say: the coarser the wool the better the quality of the skin.

The fibre structure of hides and skins also vary due to the following factors: -

(a) Type of animal species.

(b) From breed to breed within a species.

(c) Age of the animal.

(d) Sex of the animal.

(e) Feeding conditions and environment.

(f) Considerable variation over different parts of the same skin.

Figures 4, 5, 6, 7, 8 and 9 show the effect of animal species upon the fibre structure of the following types of skin - cattle hide, goatskin, sheepskin, pigskin, kangaroo skin and snakeskin respectively.

It will be noted particularly in the case of reptile such as snake, how we have a very horizontal weave pattern. This imparts very great strength but also means that it does not stretch in a shoe upper when in use like cattle hide. Therefore it is extremely important to have a good fitting for shoes at time of purchase.

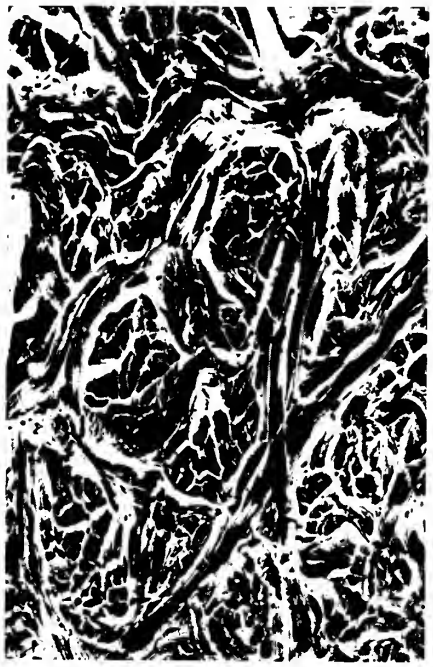


Fig. 10. Vertical section showing fibre bundles of calf skin. (After Wilson, 1928)

The corium is of major interest in leather production as it consists largely of a three-dimensional network of interwoven collagen fibres.

It will be noted from Fig. 10, showing the cross section of cattle hide that the individual fibre bundles can be split up into individual fibres, These fibres can be further split into individual fibres and these fibres can be further split into individual fibrils.

This degree of splitting and opening up of the fibre bundles into fibrils is of fundamental importance to the properties required in the final leather. (Fig. 11)

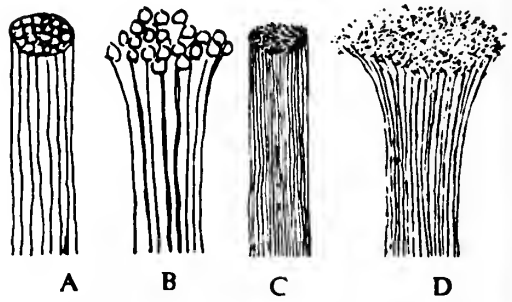


Fig. 11. Splitting of fibre bundles into fibres and fibrils.

As an anology the fibre bundle of hide and skin can be likened to textile yarn. A textile yarn spun from coarse fibres and woven compactly will give a hard fabric with a firm harsh handle, which will nevertheless be strong.

To produce a soft fabric, the textile manufacturer chooses fine fibres and spins them into yarns with a minimum of twist to give the strength required and weaves the yard loosely into a fabric.

When a tanner wishes to produce a solid firm leather he splits the fibre bundles as is indicated in Figure 11 at A, when he wishes to produce a soft pliable leather he splits them as indicated at C.

If either the fibres or fibrils become separated as in B or D the leather looses quality.

A sole leather with fibres split as in B will not be firm.

An upper leather with fibres separated as in D will be weak and without fullness and handle.

The unhairing and liming stage of leather processing is of great importance in the preparation for tannage as it decides the characteristics of the fibres which are to be tanned. In a sense, liming enables the tanner to vary the physical characteristics of the leather he produces by varying the diameter of the individual fibres that he tans. Liming will also decide the angle of weave of the fibres, that is whether the major proportion of the fibres and fibrils tend to lie parallel to the grain layer or whether they tend to run from flesh to grain.

In producing sole leather the fibre bundles should show subdivisions into fibres which have not separated, thus giving greater firmness. Also the fibre bundles of the middle section of the corium should be of a very much higher angle of weave. This will mean that the fibres have a very much greater abrasion resistance due to the fibres being

worn across their end sections rather than along their lengths.

In the case of a leather for transmission belting, which is expected to be flexible and of high tensile strength, it is desirable for the fibres to be subdivided into fibrils to obtain flexibility, also the flat or horizontal weave of the fibrils is desirable as it will enable the belt to withstand any pull to which it may be subjected in use.

When extreme flexibility is required as in picking bands which are used in the textile industry, the fibres should be split completely into fibrils.

It is of interest to consider the size of these fibres and fibrils, which may vary in thickness from 200,000 nanometers (i.e. 2,000,000 Å)
to
3,000 nanometers (i.e. 30,000 Å)

COLLAGEN

Collagen is a complex protein which in living animals is synthesized by cells called fibroblasts and is secreted into the intercellular spaces where it aggregates to form fibrils. The newly emerging collagen is water soluble but is progressively converted into less soluble and more stable forms by cross linking between acid and basic side chains of adjacent molecules, and by hydrogen bonding between the side chains and between the polypeptide backbones.

In the years preceding 1950 various molecular structures were proposed for collagen, but in the year 1951 Pauling and Corey showed these to be untenable. The currently accepted model for collagen is a coiled coil or super helix composed of three helical polypeptide chains which are coiled into a larger helix, the whole rope-like structure being stabilized by interchain hydrogen bonding and also hydrophobic bonding and electrostatic interactions. (Fig. 12)

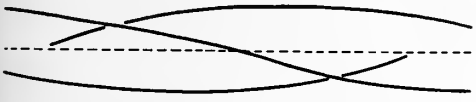


Fig. 12 showing twisting of three polypeptide chains into a rope-like super helix or coiled coil.

It has been shown that each of the three polypeptide chains in the molecule contains 1,000 amino acid residues, and that collagen contains two unique features in that every third residue in the chain is glycine and in the non-polar regions of the molecule one of the other residues in each group of three is either proline or hydroxyproline.

Collagen is characterized by the presence of the uncommon amino acids, namely hydroxyproline and hydroxlysine and the presence of very low cystine contents. (Fig. 13)

AMINO ACID COMPOSITION OF COLLAGEN (Fig.13)

(All results expressed on moisture- and ash-free basis)

Amino Acid	g.per 100 g.	g.residues per 100 g.
Total Nitrogen	18.6	
Amino-Nitrogen	0.46	-
Amide-Nitrogen	0.66	-
Neutral Amino Acids:		
Glycine	26.2	19.9
Alanine	9.5	7.6
Leucine) Isoleucine)	5.6	4.8
Valine	3.4	2.9
Pheylalanine	4.2	3.7
Tyrosine	1.4	1.3
Tryptophane	0.0	0.0
Serine	3.4	2.7
Threonine	2.4	2.0
Cystine	0.0	0.0
Methionine	0.8	0.7
Proline	15.1	12.7
Hydroxyproline	14.0	12.1
Basic Amino Acids:		
Lysine	4.5	4.0
Hydroxylsine	1.3	1.1
Arginine	8.8	7.9
Histidine	0.8	0.7
Acidic Amino Acids:		
Aspartic acid	6.3	5.5
Glutamic acid	11.3	10.0
		99.6

It may also contain a fair proportion of the amino acids in which the reactive group bears either a carboxyl group, an amide group or an amino group, which means that collagen has at the same time reactive amino acids sites which are acid, basic and non-polar.

The number of molecular chains which make up a unit fibril can be calculated and has been estimated at 20,000 for one unit fibril of cow hide collagen of 110 nanometers in dimension. It is noteworthy that they have no fixed length, although from electron microscope photomicrographs we know that they are very long in relation to their width.

It has been proved with collagen fibrils formed from solutions with a width of 100 nanometers and extending for lengths up to 10,000 nanometers that they contain up to 100,000 molecules. The rigid molecular structure and the highly ordered arrangement gives high mechanical strength to the fibrils and also explains the resistance of the collagen molecule to attack by enzymes and other reagents. There is almost no digestion of the molecule by proteolytic enzymes at temperatures below the denaturation temperature of the protein.

Collagen can occur in either a solution of the solid phase, as collagen can be denatured by heating, the hydrogen bond which stabilizes the helical structure is disrupted and the molecule is converted to a random coil formation which is known as gelatin. Very few people outside the leather industry realize that the study of the relationship between gelatin and collagen and that they can be interconverted inspired much of the early work in the synthetic fibre industry.

INFLUENCE OF STRUCTURE ON ACID AND ALKALINE SWELLING

In briefly looking at the chemistry involved in liming and tanning we find that we must look at the response of collagen fibres to alkaline and acid solutions.

When placed in water collagen takes the water up freely to about 300 per cent of its own weight. This water attaches itself to accessible active groups and peptide linkages which are not linked firmly to their opposite numbers in the neighbouring polypeptide chains.

When acid is added to water it reacts with the collagen to form a collagen salt and the sites at which these salt linkages take place are the salt linkages within the collagen.

For example, choosing hydrochloric acid: -
After the salt formation, the chloride anion remaining associated with the substituted ammonium cation will cause the water in the collagen fibres to be more highly concentrated with respect to the chloride anion than the surrounding solution. In response to the excess osmotic pressure within the collagen to which this inequality in concentration gives rise, the water passes into the fibre and the collagen swells.

A similar change occurs when sodium hydroxide is added to water in which collagen is immersed, in this case the hydroxyl anion from the alkali removes the hydrogen ions from the substituted ammmonium cations of the salt linkages and the carboxyl anion being left uncharged the polypeptide chains acquire a negative charge. The water within the collagen becomes highly concentrated with respect to the sodium cations associated with the carboxy anions and water passes into the collagen and causes it to swell.

The swelling of such fibres is restricted by the structure of the hide and skin, as is seen in the following Fig. 14.

The lower of the three graphs gives the swollen weight of goatskin and pieces of belly and butt of ox hide after they have been immersed in acid and alkaline solutions of differing pH values. At the natural pH values the original salt linkages are intact, the swelling is at a minimum. As the pieces become strongly positively charged in acid solution or strongly negatively charged in alkaline solution the water passes into the fibres - on the acid side it reaches a maximum at pH2. It then falls because the concentration of anions in the outside solution is high and is not greatly exceeded by the concentration of anions within the fibres. The curves show that at all pH values the compact goatskin (Fig. 5) swells less than the ox hide, further they show that the compact ox butt swells less than the belly part of the hide in which the fibres are less compactly woven.

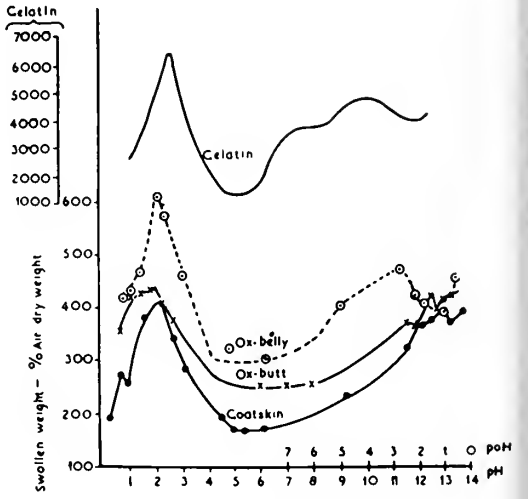


Fig. 14. The influence of hide and skin structure on water uptake at different pH values. (After Phillips, 1954)

The top curve depicts gelatin which is very closely similar in chemical constitution to collagen, from which it is produced by forcing apart the long chain molecules. The absence of ordered and oriented molecular structure facilitates the entry of water between the polypeptide chains. As the curves show in the case of gelatin, water uptake at all pH values far exceeds that of either goatskin or ox hide. Nevertheless the shape of the curve shows that the chemical mechanism causing swelling is the same in non-fibrous gelatin as in the fibrous hide and skin.

INFLUENCE OF LIMING ON WATER UPTAKE

The swelling of hides and skins in acids and alkalis is of great importance to the tanner, for if a hide or skin is highly swollen the fibres will press against one another and the interfibrillary spaces will be closed. It then becomes very difficult for tannins to diffuse into the hide and skin causing the tanning to be retarded and maybe arrested. In addition when the hides and skins swell the molecular structures of their fibres are placed under strain. During liming when the fibre bundles swell they also split into fibres, and the conditions of liming can be adjusted so that the fibres split into fibrils.

But over and above these changes, liming opens up the molecular structure of the fibrils. Such opening up, which takes the form of forcing the molecular chains apart, would enable the unit fibrils, and therefore the fibres of which they form part, to swell more freely and to take up more water (Fig. 15). It will be noticed that at all pH values the limed alkali-treated collagen takes up more water than the native untreated collagen, part of this increase becomes possible because of the loosening of the fibrous structure during liming, but the bulk is due to a loosening of the molecular structure of the fibres and fibrils. This molecular loosening or

or loss of cohesion is of great importance in tanning.

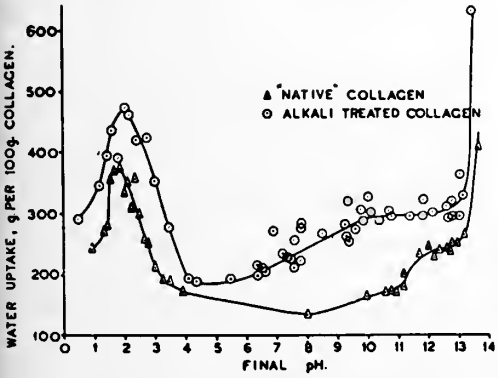


Fig. 15. Water uptakes of native and alkali-treated collagens. (After Phillips, 1954)

CHEMISTRY OF UNHAIRING

Unhairing generally is concerned with the dispersion of fibrous proteins: the tanner has to disperse the hair without weakening the collagen fibres of the hide.

Hair and wool fibres are built up from cells which are much longer than they are thick. These cells are composed mainly of keratin, a protein which is similar in chemical composition to collagen. The polypeptide chains of hair contain, however, much less proline and hydroxyproline, and they are not extended like collagen polypeptide chains, but are folded. These folded polypeptide chains of hair contain a double amino acid cystine, which is built into two polypeptide chains, linked together by a non-ionizable link. As the curves given in Fig. 16 show, this cross-linkage greatly restricts the swelling of the hair in both acid and alkaline solutions, for hair, like silk takes up much less water than collagen.

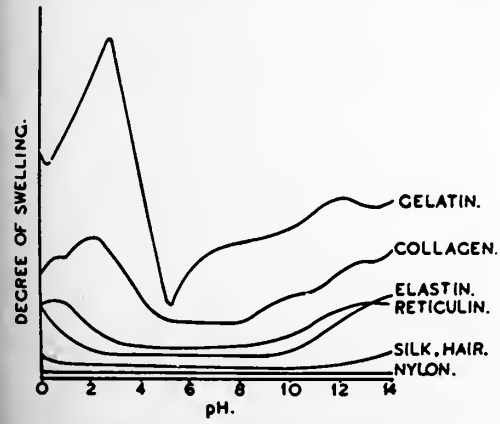


Fig. 16 The degree of swelling of fibres of different materials at different pH values. (After Phillips, 1954)

These cross-linkages can be broken chemically and then the fibre takes up water as freely as collagen.

Sodium sulphide brings this change about because it is a reducing agent and reduces the cystine linkage of the cystine and so breaks the linkage between the two polypeptide chains.

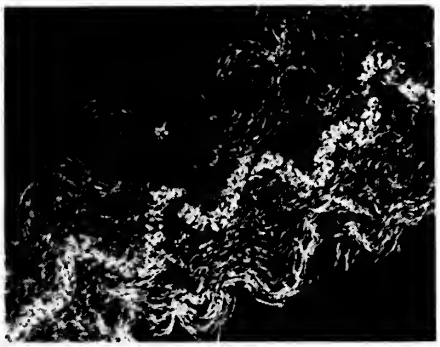
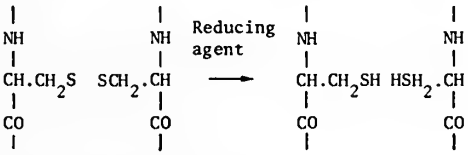
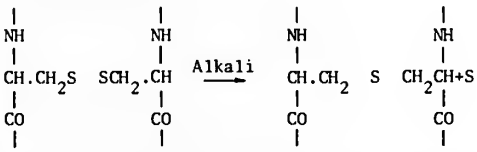


Fig. 17. A wool fibre dispersed by a solution of sodium sulphide



As is shown above each polypeptide chain retains a cystine side chain. This is an acid side chain and will therefore contribute to the osmotic swelling of the fibre and facilitate its breakdown. (Fig. 17)

Tanners found that if they put hides into a freshly made lime suspension (calcium hydroxide) it was difficult to loosen the hair later with sodium sulphide, but if they put the hides into a previously used lime liquor before liming in a new lime liquor the unhairing proceeded satisfactorily. Chemists explain this as due to the old lime containing reducing agents derived from the cystine liberated during the degradation of hair from previous packs of hides - these reducing agents would reduce the cystine cross linkages. But why should it resist the action of reducing agents? The answer is given below: -



When the hair is treated with alkali the combined cystine looses an atom of sulphur and changes to a sulphide amino acid called lanthionine - the new sulphide cross-link formed in this manner is very stable and cannot be broken by reducing or oxidizing agents.

VEGETABLE AND MINERAL TANNING

Collagen fibres are very susceptible to acid and alkaline waters, in addition bacteria can attack polypeptide chains breaking them down into their constituent amino acids. The function of tanning is to make the fibres of the hides and skins resistant to water and bacteria.

We can, of course, make a kind of leather by dehydrating raw limed hide with acetone. The acetone replaces water in the fibres, and when the hide dries and the acetone evaporates the fibres do not stick together and the hide remains pliable. If this pliable piece of hide is re-wetted and then dried it becomes hard and horny; the wet fibres on drying have stuck together. Another reason for tanning is therefore to prevent the fibres from sticking together as well as to protect them from water and bacteria.

We can, however, only make leather by protecting the molecular structure of the collagen fibres. The electron microscope and the small angle X-Ray diffraction patterns of collagen fibres have enabled us to see how tanning protects the molecular structure of the collagen.

In vegetable tanning we use extracts obtained from bark, wood, nuts, seed pods and leaves. One very important material is the tanning extract known as "Mimosa" derived from various Australian species of wattle which are today largely grown in South Africa.

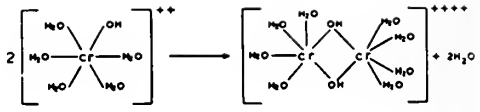
The vegetable tannins have hydroxyl and carboxyl groups which can form hydrogen bonds and salt linkages with the molecular chains of collagen. The tanning molecules can also become linked to one another by hydrogen bonds - so that we can therefore picture the first stages of tanning as an association between tannins and exposed molecular chains. This is followed by association betweened fixed tan and other tanning molecules until all the available free space has been filled, when this takes place the fibre is tanned.

Other synthetic tannins, known as syntans are also manufactured from the cheapest raw materials such as crude cresols condensed with formaldehyde, the resulting product then being sulphonated. Still more complex syntans are made by condensing simple syntans with sulphited cellulose, unfortunately these products have only about half the tanning ability of natural vegetable tannins at about twice the cost, although they can give some special effects which are not otherwise obtainable.

CHROME TANNING

Collagen however can be tanned with a far smaller quantity of mineral or inorganic tannins; for example, good shoe upper leather can be made using the most common inorganic tannin - basic chromium salts - when the pelt absorbs as little as two per cent of the tannin calculated as Cr_2O_3.

Currently single bath liquors are prepared by the reduction of solutions of sodium bichromate with sulphur dioxide or alternatively with acidified sodium bichromate solutions with glucose, the latter giving rise to the production of "masked" chrome liquors.



The above formulae give some indication of how chrome tannins are formed and aggregate. Two hydroxalated (CrOH) complexes are assumed to combine by displacement of two water molecules co-ordinated to the cationic chromium. This process can be repeated with other (CrOH) units so that long chained aggregates of hydroxylated chrome tannins could arise.

Additional complexity is introduced if the primary units are dihydroxylated $(Cr_2(OH)_2$.

Basic complexes of aluminium and zirconium can also be produced to act as tannins.

Mineral tannage stabilizes collagen by producing non-ionizable cross linkages between polypeptide chains. These arise by the co-ordination of the carboxyl groups of the aspartic and glutamic acid side chains with the chromium atoms of the cationic chromium complexes. It is possible, although still uncertain, that the terminal amino groups of the lysine and argining side chains also co-ordinate with the chromium atoms.

SCIENTIFIC ASPECTS OF USE OF LEATHER IN FOOTWEAR AND CLOTHING

The use of leather for footwear and clothing is very much bound up with its hygroscopic nature.

The tanner sometimes states that leather "breathes" and can demonstrate this by blowing air through the leather, but what is a more important constituent of leather "breathing" is its water vapour permeability, for we cannot achieve body or foot comfort unless perspiration can be lost by evaporation.

The amount of heat lose by the body or feet by evaporation of perspiration is dependent on the relative humidity of the air with which it is in contact.

Let me remind you that relative humidity is the percentage ratio of the air to the water content at saturation. When the relative humidity is low the air is dry, and when it is high the air is damp. The relative humidity depends on temperature as well as on the moisture content of the air, because the amount of water needed to attain saturation increases rapidly with temperature. The air on an autumn morning may be damp with dew forming on the grass, but by noon it may be very dry, not because the moisture content of the air has decreased, but because the temperature has increased. At dawn the temperature is low and the saturation water content is low, giving a high relative humidity and dampness, whereas at noon the temperature is high and the saturation water content is high, giving a low relative humidity and apparent dryness. The water content in a given locality is in fact surprisingly constant, and the changes from dryness to dampness are largely reflections of temperature changes.

Leather is hygroscopic and the amount of moisture it can hold depends on the relative humidity of the air with which it is in contact.

Untanned skins including our own are also hygroscopic.

From the standpoint of foot and body comfort and on account of the properties of leather fibres, it is of value to consider in detail the absorption of water vapour by collagen and leather.

The water vapour uptake of collagen at different temperatures and relative humidities is similar to those of other fibres such as nylon, silk, wool, vegetable tanned sole leather and chrome tanned upper leather (Fig. 18).

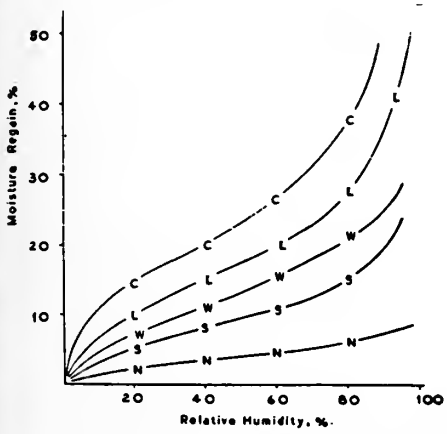


Fig. 18. The absorption of water vapour at different relative humidities by chrome leather (C); vegetable leather (L); wool (W); silk (S); nylon (N) (After Phillips, 1954)

Leather is hygroscopic and the amount of moisture it can hold depends on the relative humidity of the air with which it is in contact.

The similarity of the shapes of all the curves is a reflection of the molecular structure of the fibres. The curves are all of this particular shape, because the water vapour which enters each fibre is held in two different ways.

One being water directly linked to the molecular chains in each fibre. This water is sometimes called "bound" water and accounts for the quick initial uptake, the other being water which at higher relative humidities, becomes more loosely linked to the bound water of the fibres.

From Fig. 18 it should be noted how much more moisture at all relative humidities the chrome tanned and vegetable tanned leathers absorb than the textile fibres, wool, silk and hylon.

In addition the chrome tanned fibre absorbs more water than the vegetable tanned leather because the fibres are not packed with tan molecules.

We find that the real density of chrome leather steadily increases until it reaches a moisture content of sixteen per cent on dry weight, as the moisture content increases still further, its real density decreases.

An explanation of this initial increase and later decrease in real density with an increase in moisture content is that the regions where the chrome tannins have combined with the collagen have not been specially completely filled with tannin, and hence up to sixteen per cent moisture can pack into these regions without increasing their volume, thus the real density of the fibre increases.

Above an absorption of sixteen per cent the water begins to increase the volume of the leather fibres and the density of the leather decreases. The additional water has to make room for itself by separating the molecular chains. This increases the volume and hence the density decreases.

THERMOSTATIC PROPERTIES OF LEATHER

Not only is leather enabled by its hygroscopic properties to absorb perspiration and to breath it out to the atmosphere, but in doing so it tends to oppose rapid changes in temperature (Fig. 19).

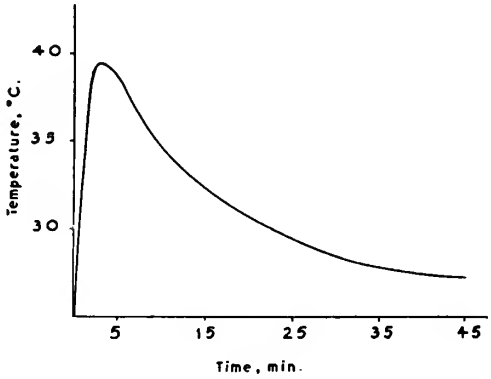


Fig. 19. The rise in temperature of chrome leather during absorption of water vapour. (After Phillips, 1954)

When damp leather looses moisture and comes to equilibrium with air of low relative humidity it becomes colder. The reason for this is that the leather supplies heat to the moisture, which is carried away as kinetic energy by the water vapour. Conversely when dry leather absorbs water vapour, it becomes warm, because as the water vapour is taken up as bound water it gives up its kinetic energy as heat.

Let us consider what happens when leather clothing or shoes are taken on a winter's day from the warm dry air of a heated but well ventilated room to the cold damp air outside.

Whilst inside the leather comes to equilibrium with the air of low relative humidity and its moisture content falls.

Outdoors, the relative humidity is high and

the leather begins to absorb water vapour, heat is liberated and this raises the temperature of the air in the leather. Temperature rises from twenty-five degrees Celsius to thirty-nine degrees Celsius in two minutes (plus fourteen degrees Celsius). It is then cooled by air passing through and even after forty minutes its temperature exceeds twenty-five degrees Celsius.

INFLUENCE OF MOISTURE CONTENT ON THE AREA AND STRENGTH OF LEATHER.

Another important aspect of leather bearing on foot comfort is its dimensional stability to changes in moisture content caused by changes in relative humidity.

In measuring changes in dimensions of chrome and vegetable tanned upper leathers, it has been found that chrome tanned leather is much more sensitive to changes in relative humidity. This means that leather shoes with chrome upper leather in damp weather will be too big and in dry weather they will be too tight to be comfortable.

This has indeed solved the riddle of the weather prophet who foretells changes in weather by the pains in his corns, as the corns are merely responding to the shrinkage of his shoes in dry weather.

The moisture content of leather fibres has a pronounced influence on their strength. The strength of chrome leather increases with its moisture content being in this regard similar to cotton, flax, hemp fibres - leather becomes weaker at lower relative humidities.

In one example of a chrome leather where the moisture content varied from zero moisture to seventy per cent moisture - at one hundred per cent relative humidity the leather strength varied from a loss of forty per cent to a gain of thirty per cent - i.e. there was a seventy per cent variation in strength from zero to seventy per cent moisture content.

In the case of vegetable tanned leather there occurred little difference in strength over the full range of moisture.

THE CONTRIBUTION MADE BY THE FIBROUS STRUCTURE OF LEATHER TO FOOD AND BODY COMFORT

Most people if asked would be puzzled why new synthetic fibres for clothing materials are not used in a continuous sheet instead of taking the trouble of converting them into fibres for spinning. The reason is that by using fibres which are spun into yarns and then woven into cloth, fabrics are produced which are light in weight and of good tear resistance and flexibility, in addition such fabrics are good insulators against heat and cold.

The fibres of fabrics entrap air which clings to the fibre surfaces and hence is more or less stationary. Stationary air is a poor conductor of heat.

The bulk density of both leather and wool felt is below 0.05 and their thermal conductivities do not greatly exceed that of air.

This is not surprising, since it can be calculated that the air space in wool felt of bulk density 0.38 per cm^3 is seventy-seven per cent of the volume of the felt. Only in the more dense leathers and felts do the higher thermal conductivities of the fibres themselves come into play, the thermal conductivities of wool being ten times that of air, while the thermal conductivity of leather fibre is somewhat higher.

The bulk density of a leather largely determines the rate at which it transmits water vapour and therefore the rate at which it carries perspiration away from the foot. It is not always realized how much perspiration leaves a normal foot.

The soles of feet perspire at five to ten times the rate at which perspiration leaves the general body surface.

The average rate of perspiration of the whole foot when at rest is six to seven milligrams per square centimetre per hour. For a man's foot of 550 cm^2 surface area this gives a total of 39.6 g. of perspiration moisture per twelve hour day. On a warm day with moderate exercise this rate is more than doubled.

The ability of leather to absorb and transmit water vapour makes a very important contribution to foot health and comfort.

CONCLUSION

In bring this address to a close, I hope that I have made you realize a little of the science involved in such an everyday commodity as leather and the hides and skins from which it is derived. I trust that I have enabled you to recognize leather as one of the fibre industries and how knowledge of the chemistry and physics of matter in fibrous form is rapidly growing, and also how the science of leather-making can explain the traditional methods of tanning.

ACKNOWLEDGEMENTS

I wish to acknowledge my early guidance from the late Dr. Henry Phillips who in 1956 in his visit to Australia highlighted this approach to leather as a fibre science.

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(Manuscript Received 25.4.77)

INTRODUCTION

The past year has been a momentous one in the annals of the Society in that it has witnessed the transfer of our activities from Science House, Gloucester Street to the new Science Centre in Clarence Street.

Although the Society's financial situation is still a matter of considerable concern to your Council, actions taken during the year have led to real economies and a reduction in the deficit. Hopefully this will continue and although a rapid improvement is unlikely in the immediate future the long-term prospects are good.

MEETINGS AND LECTURES

Council continued its policy of inviting speakers expert in their field to deliver lectures at our monthly meetings, the lectures being pitched at the level of the well-informed layman. All meetings and lectures held during the year were well supported, the average attendance in excess of 45 is considered to be a vindication of this policy as well as being a reflection of the excellent standard maintained by our lecturers.

The following meetings and lectures were held during the year, the venue for those from April through to August being the Large Hall, Science House, whereas for those held subsequently it was the Auditorium, Science Centre.

April 7th: Annual General Meeting and Presidential Address, "Leather - Why is it so?", Mr. E.K. Chaffer, Director, W. Chaffer and Sons Pty. Ltd.

May 5th: "Island Arcs and Ore Deposits", Professor R.L. Stanton, Department of Geology, University of New England.

June 2nd: "Human Nutrition - Science or Trans-Science", Mr. M.V. Tracey, Chief, C.S.I.R.O., Division of Food Research.

July 7th: "Science and Art: Some Issues", Mr. Elwyn Lynn, Curator, Power Gallery of Contemporary Art, the Power Institute of Fine Arts, University of Sydney.

August 4th: "Some Spacecraft I have known", Dr. K.G. McCracken, Chief, C.S.I.R.O., Division of Mineral Physics.

September 1st: "Light and Colour", Dr. W.R. Blevin, Chief Research Scientist, C.S.I.R.O., National Measurement Laboratory.

October 6th: "Some Possible Staging Places in Aboriginal Australian Migration from South-East Asia", Emeritus Professor N.W.G.Macintosh, Department of Surgery, University of Sydney.

November 3rd: "Aboriginal Health and its Relationship to Vitamin C", Dr. Archie Kalokerinos.

December 1st: Symposium, "People, Planning and the Environment", Mr. R.P. Murphy, Assistant Director, Pollution Control, N.S.W. State Pollution Control Commission; Dr. L.L. Pownall, Chairman, N.S.W. Planning Environment Commission; Dr. A.J. Sutton, Director, Bureau of Crime Statistics and Research, N.S.W. Department of Attorney General and Justice.

In addition, the following functions were held within the University of Sydney:

June 16th: "An Evening at the Macleay", Dr. P. Stanbury, Director, and Staff, the Macleay Museum.

July 15th: Liversidge Research Lecture 1976: "Coordination, Topology and Structure in Metal Oxides", Professor R.L. Martin, Research School of Chemistry, Australian National University.

ANNUAL DINNER

The Annual Dinner was held in the Sydney Hilton Hotel on 15 March and was attended by 106 members and guests. The guest speaker was Dr. Harry Windsor, F.R.A.C.S., the title of his address being "Surgery in Today's Society".

AWARDS

The following Awards for 1976 were made:

Edgeworth David Medal:	Professor R.H. Street
The Society's Medal:	Mr. E.K. Chaffer
Clarke Medal:	Dr. Lilian R. Fraser
James Cook Medal:	No Award
Liversidge Research Lectureship:	Prof. R.L. Martin
Archibald D. Olle Prize:	Dr. L.A. Drake

Summer School in Medicine Essay Prizes: Mr. S. Harvey, Miss K. Byron, Miss E. Ratanayagam.

SUMMER SCHOOLS

The two Summer Schools held during January for fifth-form students again proved to be most rewarding for all concerned. The school having chemistry as its theme and entitled, "Chemistry and Colour", was held, as previously, at Macquarie University. It was attended by 59 students from 43 secondary schools. The second school entitled, "Medicine and Health Services", attracted 66 students from 63 schools. This school was based at Royal Prince Alfred Hospital and included visits to other medical institutions as well as State Government laboratories.

MEMBERSHIP

The membership at 31 March was: Honorary Members, 11; Life Members, 35; Members, 365; Associates, 60; Company Member, 1. The number of applications for membership received during the year was disappointingly small, none being received through the Summer Schools, and surely must be a reflection of the prevailing economic climate. Emeritus Professor P.A. Elkin and Sir Robert Price were elected to Honorary Membership.

PUBLICATION

Volume 109 of the Journal and Proceedings was published during the year using the "type-it-yourself" process. This innovation has proved most successful and has succeeded in holding publication costs for the time being.

Dr. Day made on the Society's behalf a written submission to and personal appearance at the Industries Assistance Commission enquiry into the publishing industry. The Commission has yet to present its report to the Government.

LIBRARY

Demand on the library's resources was strongly sustained during the year. 2368 items were received and processed. These comprised periodicals on exchange from some 356 societies and institutions, together with donations and periodicals purchased. 181 members, societies and other organizations used the library facilities during the year. Restricted finance allowed the library to be opened only two full days per week. The Librarian, Mrs. G. Proctor, maintained all the library's services under difficulty, especially during the transfer to Science Centre. The Library was moved to its new location in the 2nd week of December by the intensive effort of volunteer members and a team of students.

FINANCE

The accompanying financial statements show that a deficit of $11,771 was incurred on operations during the year. This decline in the Society's liquid resources was regretfully foreseen by the Council, although unexpected factors made it larger than was budgeted for. No Government grant was received (the first such omission in about 110 years), and the Science Centre project was still in an establishment phase and therefore did not contribute any return to the Society. An additional burden, in excess of $5000, resulted from the need to move the office and library to the Science Centre late in the year, about two years earlier than previously anticipated.

The resignation in April of the executive secretary, Mrs. V. Lyle, to proceed overseas, while much regretted, provided an opportunity to effect significant economy in salary payments by restricting office hours to twelve per week. A short trial quickly showed that no useful saving could be achieved by reduction of the librarian's hours, without very seriously disrupting the library service. The greatest possible economies were applied wherever practical to all the operations of the Society and the voluntary work of councillors, ordinary members and friends of the Society assisted considerably in minimizing the deficit. Operations generating their own income were required to at least break even. The change to offset printing of the Journal and Proceedings saved about $5000.

The net result of the year's operations is that the balance of the Resumption Reserve, established to support the Society following cessation of income from Science House, has now been exhausted and the remainder of the deficit was financed from the Society's general funds. (In comparing the 1976 figures with those for 1975 in the financial statements it should be noted that the 1975 financial year covered only ten months due to the change in closing date to 31st December.)

The response to the appeal for donations to assist in the continuation of long-standing subscriptions to journals for the library was most gratifying, yielding $1300. The bulk of this was invested to provide continuing income in future years. All donations of $2 or more to the "Royal Society of New South Wales Library Fund" are tax-deductible and will help to cover the cost of housing and operating the library. In 1977 this is anticipated to be close to $5000.

SCIENCE CENTRE

The new Science Centre was officially opened on 23 March, 1977, by His Excellency the Governor of New South Wales, Sir Roden Cutler. Lady Cutler was also present as were Mr. N. Wran, the Premier of N.S.W., Sir Eric Willis, Leader of the Opposition in State Parliament, and other distinguished guests.

The Centre is now fully operational, the Society's Office and Library being housed on the 6th floor. Also on this floor is the office of Science House Pty. Ltd. which, in addition to managing the Science Centre, provides secretarial services for kindred societies.

ROYAL SOCIETY ASSOCIATES

Two years ago when this group was formed, largely from students who had attended the previous Summer Schools, Council held high hopes that it would prove to be a source of new members and life-blood for the Society. Unfortunately this hope has not been realized and this year the group has been forced into recess through lack of support.

ACKNOWLEDGEMENTS

Council wishes to acknowledge the excellent work carried out during the year by Mrs. Judith Day who attends to our secretarial affairs, to Mrs. Grace Proctor, the Assistant Librarian and Mrs. C. McKay. It also wishes to record its appreciation for the work carried out by all who were responsible for the success of the Summer Schools and monthly lectures. In addition, Council wishes to acknowledge the work of Dr. Alan Day, who managed the transfer of the Society from Science House, and also that of all his recruits who ably assisted in this task.

CORRIGENDUM

Report of Council for Year Ended 31st March, 1976.

From the section headed Awards delete, "Liversidge Research Lectureship: Dr. R.L. Martin", and substitute, "Clarke Memorial Lecture, 1975: Dr. K.S.W. Campbell".

ANNUAL REPORT OF NEW ENGLAND BRANCH OF THE ROYAL SOCIETY OF NEW SOUTH WALES

OFFICERS

Chairman : S.C. Haydon
Secretary Treasurer : R.E. Gould
Committee : R.L. Stanton, N.T.M. Yeates, R.D.H. Fayle, N.H. Fletcher
Representative on Council : N.T.M. Yeates

The following meetings were held :

18th June, 1976 :	"Metals in Water", Dr. D.J. Swaine, C.S.I.R.O. Division of Mineralogy, Sydney.
21st October, 1976 :	"Some Spacecraft I have known", Dr. K.G. McCracken, C.S.I.R.O. Division of Mineral Physics, Sydney.

FINANCIAL STATEMENT

Balance as at 31st March, 1976	$278.48	
Credit - Interest to 29.6.76	4.91	
- Interest to 31.12.76	4.11	
		$287.50
Debit - Air Fare for speaker	$ 69.00	
- Miscellaneous	14.00	
		$ 83.00
Balance as at 31st December, 1976		$204.50

ANNUAL REPORT OF THE SOUTH COAST BRANCH OF THE ROYAL SOCIETY OF NEW SOUTH WALES

OFFICERS

Chairman : B. Clancy
Secretary : G. Doherty
Representative on Council : G. Doherty.

No meetings of the Branch were held during the year.

FINANCIAL STATEMENT

Balance as at 31st March 1976	$46.20
Credit : Accumulated Interest	$ 2.05
Balance as at 31st December 1976	$48.25

CITATIONS

EDGEWORTH DAVID MEDAL

The Edgeworth David Medal for 1976 is awarded to Associate-Professor Ross Howard Street for distinguished contributions to mathematical research. This award is restricted to scientists under the age of 35.

Associate-Professor Street is a graduate of the University of Sydney and is now on the staff of Macquarie University where he rose from lecturer to associate-professor in 5 years. He has made major contributions to category theory, and has published an elegant analysis of the formal theory of monads. Already his published work marks him as a young scientist of exceptional understanding in difficult fields; where others have been indefinite, he has been decisive. Participation in overseas conferences has given prominence to his work, and led Professor S. Eilenberg of Columbia University, New York, to say of him: "This is the coming generation".

Associate-Professor Street's work is of outstanding quality and depth, and well worthy of this award.

THE CLARKE MEDAL

The Clarke Medal for 1976 for distinguished work in the natural sciences is awarded to Dr. Lilian Ross Fraser.

As a Linnean Macleay Fellow, Dr. Fraser initiated her studies on the life history, morphology and physiology of "sooty moulds", which culminated in the award of a D.Sc. from the University of Sydney. She joined the Department of Agriculture in the early 1940's and continued research on fungi and fungal diseases of many native and crop plants. As a result of her work on the fungi causing root-rot in citrus and of her development of disease-resistant stocks, the citrus industry in the irrigation areas of the Murray and Murrimbidgee was saved from near-disaster about 1950.

Later work dealt with the virology of citrus and diseases affecting grapes, vegetables and ornamentals. She is held in high regard by her fellow scientists and by the man on the land, surely an important accomplishment. Internationally she is known for her research on the virology and pathology of citrus. At the invitation of the Government of India, she reported on problems of citrus-growing and disease control.

Dr. Fraser is a past-President of the Linnean Society and has been active in the profession of botany. She retired recently from the Biological and Chemical Research Institute of the New South Wales Department of Agriculture, where she had been Chief Biologist.

Dr. Fraser rightly joins the eminent group of Clarke medallists.

THE SOCIETY'S MEDAL

The Society's Medal for 1976 is awarded to Mr. Edric Keith Chaffer for service to science and to the Society.

Mr. Chaffer's interest in the Royal Society of New South Wales started at school where he perused the Journal in the school library. As a schoolboy he attended the 1949 Clarke Memorial Lecture by Dr. F.W. Whitehouse, and was elected to membership in 1954. Since then he has shown a constant interest in the Society and continues to work for it. He is a past-President and has served as Honorary Secretary, Council member, chairman of the Section of Geology, director of Science House Pty. Ltd. and on library and publication committees. His extensive knowledge of the history of the Royal Society is constantly of value to members of the Council.

As a director of W. Chaffer and Sons Pty. Ltd., a tanning and leather-finishing company founded in 1887, Mr. Chaffer keeps a wide interest in leather and in the leather trade. For several years he was senior lecturer (part time) in the School of Tanning at the Sydney Technical College, and is active in the Leather Industry Research Association and other associations connected with leather. He is a member of the American Leather Chemists' Association, the Society of Leather Technologists and Chemists, and of the Verein für Gerberei-Chemie und-Technik. Clearly he is a man of standing in his profession.

Following the study of geology at school, Mr. Chaffer did a part-time course in geology at the Sydney Technical College. He is a member of the Geological Society of Australia.

Edric Chaffer is a dedicated member of the Royal Society of New South Wales. All aspects of our work

interest him and he contributes freely with his knowledge and participation. His service to our Society and to the profession of leather science makes him a worthy recipient of the Society's Medal.

ARCHIBALD D. OLLE PRIZE

The Archibald D. Olle Prize is awarded to Dr. Lawrence A. Drake for his paper entitled "Seismic Risk in Australia", which was judged the best paper submitted during 1976 and published in the Journal of the Society. Dr. Drake graduated B.A. with Honours in mathematics and B.Sc. in physics from the University of Melbourne. He then studied at the University of California, Berkley campus, where he graduated M.A. and Ph.D.

At present Dr. Drake is Director of the Riverview Observatory and Senior Lecturer in the School of Earth Sciences at Macquarie University. His research interests are mainly seismology, the finite element method and surface wave responses of structures.

SUMMER SCHOOL IN MEDICINE

In January 1977, 66 selected students from Year 11 in Sydney schools attended a summer school in medicine arranged for the Royal Society of New South Wales by Dr. Lowenthal and Mrs. Krysko v. Tryst.

We asked the students to submit essays based on what they had learnt during the week. These essays were sent to Dr. Lowenthal in Paris and he has judged them. It is my pleasure to announce the names of those who sent in the best 3 essays and to present each student with a copy of our Centenary Volume.

First	Mr. Steven Harvey
Equal Second	Miss Kathryn Byron
	and Miss Estelita Ratanayagam

Financial Statements for 1976

AUDITOR'S REPORT TO THE MEMBERS

In our opinion:

(a) the attached balance sheet and income and expenditure account are properly drawn up in accordance with the Rules of the Society and so as to give a true and fair view of the state of affairs of the Society at 31st December 1976 and of the results of the Society for the year ended on at date; and

(b) the accounting records and other records, and the registers required by the Rules to be kept by the Society have been properly kept in accordance with the provision of those Rules.

DOUGLAS R. WYLIE, PUTTOCK, KIELY AND CO.
Chartered Accountants.

By ALAN M. PUTTOCK
Registered under the Public Accountants
Registration Act, 1945 as amended.

BALANCE SHEET to 31/12/76

	RESERVES			
9,040	Library Reserve(note 2(i))			7,200
424,564	Resumption Reserve (note 2(ii))			416,991
92,797	LIBRARY FUND (note 2(iii))			93,822
806	LONG SERVICE LEAVE FUND			806
10,652	TRUST FUNDS (note 4)			11,374
37,822	ACCUMULATED FUNDS			35,742
$575,681	TOTAL RESERVES & FUNDS			$565,935
	CURRENT ASSETS			
15	Petty Cash Imprest		187	
153	Debtors for Subscriptions	1,075		
153	Less Provision for Doubtful Debts	1,075	-	
1,409	Other Debtors & Prepayments		1,865	
12,534	Interest Bearing Deposit		7,426	
10,108	Cash at Bank		10,420	
$ 24,066				19,898
	Less: CURRENT LIABILITIES			
8,539	Sundry Creditors & Accruals		13,684	
4	Life Members Subscriptions - Current Portion		4	
127	Membership Subscriptions Paid in Advance		40	
1,966	Subscription to Journal Paid in Advance		1,362	
$ 10,636				15,089
$ 13,430	NET CURRENT ASSETS			4,809
	Add: FIXED ASSETS			
2,122	Furniture and Office Equipment - at cost less Depreciation		7,888	
2	Lantern - at cost less Depreciation		2	
13,600	Library - 1936 Valuation		13,600	
14	Pictures - at cost less Depreciation		13	
$ 15,738				$ 21,503

$ 29,168			$ 26,312
	Add: INVESTMENTS		
16,680	Commonwealth Bonds & Inscribed Stock	27,180	
20,000	Loans on Mortgage	-	
400	Debenture Stock	-	
$37,080			27,180
	Add: ASSOCIATED CORPORATIONS (note 3)		
1	Shares - at cost	1	
509,490	Advances and Loans - Unsecured	512,495	
$509,491			$512,496
$575,739			$565,988
	Less: NON-CURRENT LIABILITIES		
	Life Members Subscriptions -		
58	Non-Current Portion		53
$575,681	NET ASSETS		$565,935

D.J. Swaine, President A.A. Day, Honorary Treasurer

STATEMENT OF ACCUMULATED FUNDS

For the Year Ended 31 December 1976

13,583	DEFICIT for year	11,771
87,583	Donations and Interest to Library Fund	1,303
3,767	Science House Partnership	-
1,438	Transfer from Library Reserve	1,840
-	Transfer from Library Fund	278
29,407	Transfer from Resumption Reserve	7,573
16,793	Accumulated Funds-Beginning of Year	37,822
$125,405	AVAILABLE FOR APPROPRIATION	37,045
87,583	Transfer to Library Fund	1,303
$ 37,822	ACCUMULATED FUNDS - Current Year	$ 35,742

NOTES TO AND FORMING PART OF THE ACCOUNTS
for the year ended 31st December, 1976.

1. SUMMARY OF SIGNIFICANT ACCOUNTING POLICIES

Set out hereunder are the significant accounting policies adopted by the Society in the preparation of its accounts for the year ended 31st December, 1976. Unless otherwise stated, such accounting policies were also adopted in the preceding year.

(a) Accounting Period

In order to rationalise the time between the close of the Society's financial year and the holding

of the Annual General Meeting the Society's accounting period has been changed from 1st March - 28th February to 1st January - 31st December.

As a result of the above change in policy the figures for the current period represent 12 months operations while the comparative figures shown represent 10 months operations.

(b) Depreciation

Depreciation is calculated on a written down value basis so as to allow for anticipated repair costs in later years.

The principal annual rates in use are:

Furniture	7.5%
Office equipment	15.0%

(c) Deficit from Operations

The balance of the Resumption Reserve, after lending $416,990 to Science House Pty. Ltd., has been allocated to meet operating deficits. (see also notes 2 (ii) and 3).

2. MOVEMENTS IN PROVISIONS AND RESERVES

(i) Library Reserve

	1975 $	1975 $	1976 $	1976 $
Balance at 1st January 1976		10478		9040
Less Transferred to accumulated funds re:				
Library recataloguing	1292		1840	
Typing and printing subject index	681		-	
	1973		1840	
Less donations towards printing subject index	535		-	
		1438		1840
Balance at 31st December 1976		$9040		$7200

(ii) Resumption Reserve

Balance at 1st January 1976		453971		424564
Less Transferred to accumulated funds re:				
Operating deficit prior years	15994		-	
Operating deficit current year	13413		7573	
		29407		7573
Balance at 31st December 1976		$424564		$416991
Represented by:				
Shares in associated coporation		1		1
Loans to associated corporation		416990		416990
Short term deposits		7573		-
		$424564		$416991

2. MOVEMENTS IN PROVISIONS AND RESERVES Continued

(iii) Library Fund

	1975 $	1976 $
Balance at 1st January 1976	5214	92797
Add donations and bank interest	87583	1303
	92797	94100
Less Library purchases	-	278
Balance at 31st December 1976	$92797	$93822
Represented by:		
Cash at bank	297	22
Loans to associated corporation	92500	92500
Commonwealth Bonds	-	1300
	$92797	$93822

3. ASSOCIATED CORPORATIONS

The Society has entered into a joint venture with the Linnean Society for the establishment of a Science Centre for New South Wales and to facilitate this, a company, Science House Pty. Limited has been formed in which each Society has 50% interest.

Advances and loans to the company have been on an interest free basis repayable at call. No material repayments are anticipated prior to 31st December, 1977.

	1975 $	1976 $
Total amount advanced	509490	512495
Representing:		
Resumption reserve	416990	416990
Library fund	92500	92500
Accumulated funds	-	3005
	$509490	$512495

4. TRUST FUNDS

	1975	Clarke Memorial	Walter Burfitt Prize
	$	$	$
Capital	7000	3600	2000
Revenue income for period	616	337	187
Less expenditure	360	-	-
	256	337	187
Balance from 1975	3396	954	912
Total Revenue	$3652	$1291	$1099
Total Trust Funds	$10652	$4891	$3099

4. TRUST FUNDS Continued

	Liversidge Bequest $	Olle Bequest $	Total $
Capital	1400	-	7000
Revenue Income for Period	131	117	772
Less Expenditure	50	-	50
	81	117	722
Balance from 1975	548	1238	3652
Total Revenue	$629	$1355	$4374
Total Trust Funds	$2029	$1355	$11374

FUNDS STATEMENT FOR THE YEAR ENDED 31ST DECEMBER 1976

	1975 $	1975 $	1976 $	1976 $
SOURCE OF FUNDS				
Donations and interest to library fund		87583		1303
Withdrawal of investments		-		9900
Trust fund income		616		772
Reduction in working funds		9624		7607
Refund of capital Science House partnership		3767		-
		$101590		$ 19582
APPLICATION OF FUNDS				
Operating deficit for the year	13583		11771	
Less:				
Items not involving the outlay of funds in the current period:				
Depreciation of fixed assets	187		252	
Provision for doubtful debts	170		1014	
Funds applied to operations		13226		10505
Loan to associated company		87500		3005
Purchase of furniture and equipment		100		6017
Reclassification of life members subscriptions in advance		4		5
Increase in investments		400		-
Trust fund expenses		360		50
		$101590		$ 19582

FINANCIAL STATEMENTS

INCOME AND EXPENDITURE ACCOUNT

For the Year Ended 31 December 1976

	INCOME			
6,051	Membership Subscriptions - Ordinary			7,298
6	Membership Subscriptions - Life Members			5
158	Application Fees			27
6,215				7,330
1,950	Subscriptions to Journal			2,923
2,000	Government Subsidy			-
705	Donations - Printing Journal & Publications			117
10,870	Total Membership & Journal Income			10,370
4,136	Interest Received			4,152
1,924	Sale of Reprints			567
476	Sale of Back Numbers			60
123	Sale of Other Publications			343
4	Donations - General			-
-	Annual Social Surplus			27
-	Summer School Surplus			739
17,533				16,258
	Less : EXPENSES			
800	Accountancy Fees		920	
-	Advertising		48	
244	Annual Social		-	
110	Audit Fees		110	
142	Cleaning		136	
187	Depreciation		252	
119	Electric Light & Power		131	
96	Entertainment Expenses		73	
	Journal & Publication Costs			
9,073	Printing - Current Year Volume	4,645		
681	Printing - Other Publications	372		
175	Binding	-		
747	Wrapping & Postage	887		
			5,904	
-	Legal Costs		250	
409	Library Purchases		599	
1,292	Library Recataloguing		1,840	
-	Library Relocation		1,967	
463	Miscellaneous Expenses		63	
715	Postage		973	
822	Printing and Stationery - General		417	
170	Provision for Doubtful Debts		1,014	
4,006	Rent		4,767	
328	Repairs and Maintenance		297	
9,529	Salaries		6,946	
-	Secretarial Services		745	
557	Superannuation Contributions - Employees		216	
451	Telephone		361	
31,116				28,029
13,583	DEFICIT for the year			11,771

AUSTRALASIAN MEDICAL PUBLISHING CO. LTD.,
71-79 ARUNDEL ST., GLEBE, N.S.W., 2037
1977

THE ROYAL SOCIETY OF NEW SOUTH WALES

The Society originated in the year 1821 as the Philosophical Society of Australasia. Its main function is the promotion of Science through the following activities: Publication of results of scientific investigation through its Journal and Proceedings; the Library; awards of Prizes and Medals; liaison with other Scientific Societies; Monthly Meetings; and Summer Schools for Senior Secondary School Students. Special Meetings are held for the Pollock Memorial Lecture in Physics and Mathematics, the Liversidge Research Lecture in Chemistry, and the Clarke Memorial Lecture in Geology.

Membership is open to any interested person whose application is acceptable to the Society. The application must be supported by two members of the Society, to one of whom the applicant must be personally known.

Membership categories are:

Ordinary Members: $18.00 per annum plus $3 application fee.

Absentee Members: $15.00 per annum plus $3 application fee.

Associate Members (spouses of members and persons under 25 years of age): $5.00 per annum plus $2.00 application fee.

Associate Members (with Journal): $12.00 per annum plus $2 application fee.

Subscription to the Journal, which is published in four Parts per year, issued twice yearly in May and November, for non-members is $22 p.a. plus postage.

For application forms for membership and enquiries *re* subscriptions, write to:

The Royal Society of New South Wales,
Science Centre,
35 Clarence Street,
Sydney, 2000, N.S.W.

The Society welcomes manuscripts of research (and occasional review articles) in all branches of science, art, literature and philosophy, for publication in the Journal and Proceedings.

Manuscripts will be accepted from both members and non-members, though those from the latter should be communicated through a member. A copy of the Guide to Authors is obtainable on request and manuscripts may be addressed to the Honorary Secretary (Editorial) at the above address.

Contents

AUSTRALASIAN MEDICAL PUBLISHING CO. LTD.,
71-79 ARUNDEL ST., GLEBE, N.S.W., 2037
1977

NOTICE TO AUTHORS

A "Style Guide to Authors" is available from the Honorary Secretary, Royal Society of New South Wales, 157 Gloucester Street, Sydney, N.S.W., 2000, and intending authors *must* read the guide before preparing their manuscript for review. The more important requirements are summarized below.

GENERAL

Manuscripts should be addressed to the Honorary Secretary (address given above).

Manuscripts submitted by a non-member must be communicated by a member of the Society.

Each manuscript will be scrutinised by the Publications Committee before being sent to an independent referee who will advise the Council of the Society on the acceptability of the paper. In the event of rejection, manuscripts may be sent to two other referees.

Papers, other than those specially invited by Council, will only be considered if the content is substantially new material which has not been published previously, has not been submitted concurrently elsewhere, nor is likely to be published substantially in the same form elsewhere. Well-known work and experimental procedure should be referred to only briefly, and extensive reviews and historical surveys should, as a rule, be avoided. Letters to the Editor and short notes may also be submitted for publication.

Original papers or illustrations published in the Journal and Proceedings of the Society may be reproduced only with the permission of the author and of the Council of the Society; the usual acknowledgments must be made.

Offset printing with "Typeset-it-Yourself" preparation of a master manuscript suitable for photography is used in the production of the Journal. Authors will be supplied with a set of special format paper. An IBM Selectric (Golf Ball) typewriter with ADJUTANT 12 typeface must be used. Biological and reference material are shown in *Light Italic*. Symbol 12 has most type required for mathematical expressions and formulae. Detailed instructions for the typist are included in the Style Guide.

PRESENTATION OF INITIAL MANUSCRIPT FOR REVIEW

Typescripts should be submitted on heavy bond A4 paper. A second copy of both text and illustrations is required for office use. This may be a clear carbon or photographic copy. Manuscripts, including the abstract, captions for illustrations and tables, acknowledgments and references should be typed in double spacing on one side of the paper only.

Manuscripts should be arranged in the following order: title; name(s) of author(s); abstract; introduction; main text; conclusions and/or summary; acknowledgments; references; appendices; name of Institution/Organisation where work carried out/or private address as applicable; date manuscript received by the Society. A table of contents should also accompany the paper for the guidance of the Editor.

Spelling follows "The Concise Oxford Dictionary".

The Systeme International d'Unites (SI) is to be used, with the abbreviations and symbols set out in Australian Standard AS1000.

All stratigraphic names must conform with the Australian Code of Stratigraphic Nomenclature (revised fourth edition) and must first be cleared with the Central Register of Australian Stratigraphic Names, Bureau of Mineral Resources, Geology and Geophysics, Canberra. The letter of approval should be submitted with the manuscript.

Abstract. A brief but fully informative abstract must be provided.

Tables should be adjusted for size fit the format paper of the final publication. Units of measurement should always be indicated in the headings of the columns or rows to which they apply. Tables should be numbered (serially) with Arabic numerals and must have a caption.

Illustrations. When submitting a paper for review all illustrations should be in the form and size intended for insertion in the master manuscript If this is not readily possible then an indication of the required reduction (such as reduce to ½ size) must be cleary stated.

Note: There is a reduction of 30% from the master manuscript to the printed page in the journal.

Maps, diagrams and graphs should generally not be larger than a single page. However, large figures can be printed across two opposite pages.

Drawings should be made in black Indian ink on white drawing paper, tracing cloth or light-blue lined graph paper. All lines and hatching or stippling should be even and sufficiently thick to allow appropriate reduction without loss of detail. The scale of maps or diagrams must be given in bar form.

Half-tone illustrations (photographs) should be included only when essential and should be presented on glossy paper (no negative is required).

Diagrams, graphs, maps and photographs must be numbered consecutively with Arabic numerals in a single sequence and each must have a caption.

References are to be cited in the text by giving the author's name and year of publication. References in the reference list should follow the preferred method of quoting references to books, periodicals, reports and theses, etc., and be listed alphabetically by author and then chronologically by date.

Abbreviations of titles of periodicals shall be in accordance with the International Standard Organization ISO4 "International Code for the Abbreviation of Titles of Periodicals" and International Standard Organization ISO833 "International List of Periodical Title Word Abbreviations" and as amended.

Appendices should be placed at the end of the paper, be numbered in Arabic numerals, have a caption and be referred to in the text.

Reprints. An author who is a member of the Society will receive a number of reprints of his paper free. An author who is not a member of the Society may purchase reprints.

(Report of Council, 31st March, 1977—continued from Vol. 110, Parts 1 and 2)

Abstract of Proceedings, Year Ending 31st December, 1976

LOCATION

Large Hall, Science House, 157 Gloucester Street, Sydney.

APRIL 7TH

109th Annual General Meeting. The President Mr. E.K. Chaffer was in the chair and 40 members and visitors were present. 4 new members were elected and Council announced the admittance of 5 new associate members. Council also announced the election, by Council, to Honorary Membership of Professor Samuel W. Carey. Council advised of changes in subscriptions, the new rates being Ordinary Membership $18.00, Absentee Membership $15.00, Associate Membership $5.00, Associate Membership (with Journal) $12.00, subscriptions to Journal (non-members and institutions) $22.00 plus postage.

The Clarke Medal was awarded to Dr. J.N. Jennings; the Edgeworth David Medal to Dr. F.J. Ballard; the James Cook Medal to Dr. A. Walsh and the Society's Medal to Mr. W.H. Robertson.

Messrs. D.R. Wylie, Puttock and Kiely were elected Auditors.

The Presidential address "Leather - Why is it so?" was given by Mr. E.K. Chaffer.

The incoming President, Dr. D.J. Swaine was installed and introduced to members.

MAY 3RD

891st General Monthly Meeting. The President Dr. D.J. Swaine was in the chair and 68 members and visitors were present. 6 new members were elected and Council announced the admittance of 1 new associate member.

An address "Island Arcs and Ore Deposits" was given by Professor R.L. Stanton, Department of Geology, University of New England.

JUNE 2ND

892nd General Monthly Meeting. The President Dr. D.J. Swaine was in the chair and 45 members and visitors were present. Council announced the admittance of 1 new associate member.

An address "Human Nutrition - Science or Trans-Science" was given by Mr. M.V. Tracey, Chief, Division of Food Research, C.S.I.R.O.

JULY 7TH

893rd General Monthly Meeting. The President Dr. D.J. Swaine was in the chair and 47 members and visitors were present. Council announced the admittance of 1 new associate member.

An address "Science and Art: Some Issues" was given by Mr. Elwyn Lynn, Curator, Power Gallery of Contemporary Art, University of Sydney.

AUGUST 4TH

894th General Monthly Meeting. The President Dr. D.J. Swaine was in the chair and 53 members and visitors were present.

An address "Some Spacecraft I have known" was given by Dr. K.G. McCracken, Chief, Division of Mineral Physics, C.S.I.R.O.

LOCATION

Auditorium, Science Centre, 35 Clarence Street, Sydney.

SEPTEMBER 1ST

895th General Monthly Meeting. The President Dr. D.J. Swaine was in the chair and 30 members and visitors were present. 1 new member was elected and Council announced the admittance of 1 new associate member.

The President made a few remarks appertaining to the successful completion of the Science Centre and welcomed members and visitors to this, the first meeting in the new home of the Society.

An address "Light and Colour" was given by Dr. W.R. Blevin, Chief Research Scientist, National Measurement Laboratory, C.S.I.R.O.

OCTOBER 6TH

896th General Monthly Meeting. Mr. E.K. Chaffer, Vice-President, was in the chair and 43 members and visitors were present. 1 new member was elected.

An address "Some Possible Staging Places in Aboriginal Migration from South East Asia" was given by Emeritus Professor N.W.G. Macintosh, Department of Surgery, University of Sydney.

NOVEMBER 3RD

897th General Monthly Meeting. The President Dr. D.J. Swaine was in the chair and 26 members and visitors were present.

Mr. W.H. Robertson presented a few comments illustrated by photographs, on the total eclipse of the October 23.

An address "Aboriginal Health and its Relationship to Vitamin C" was given by Dr. Archie Kalokerinos.

DECEMBER 1ST

898th General Monthly Meeting. The President Dr. D.J. Swaine was in the chair and 41 members and visitors were present. Council announced that it had elected to Honorary Membership Sir Robert Price, Chairman of C.S.I.R.O., and Emeritus Professor P.A. Elkin.

A symposium was held with the theme "People, Planning and the Environment". The panel of speakers comprised Dr. A.J. Sutton, Director, Bureau of Crime Statistics, N.S.W. Department of Attorney-General and Justice; Dr. L.L. Pownall, Chairman, N.S.W. Planning and Environment Commission; Mr. R.P. Murphy, Assistant Director, Pollution Control, N.S.W. State Pollution Control Commission.

LOCATION

The Macleay Museum, University of Sydney.

JUNE 16TH

Members and gusests attended a private viewing of the exhibition "The Moving Frontier; Aspects of Aboriginal European Interaction" and of an exhibition on an aboriginal theme " A History of Australia". The Curator of the Museum, Dr. Peter Stanbury, gave a talk on the exhibitions.

LOCATION

Lecture Theatre No. 4, School of Chemistry, University of Sydney.

JULY 15TH

The Liversidge Lecture for 1976 was given by Professor R.L. Martin, Professor of Inorganic Chemistry, Research School of Chemistry, Institute of Advanced Studies, Australian National University, the title of the address being "Co-ordination, Topology and Structure in Metal Oxides".

Obituaries

Ida Alison Browne

Ida Alison Browne died in Sydney on October 21st, 1976 after a long illness. She was born at 175 Sutherland St., Paddington on August 16, 1900 to the wife of William G. Brown.

Drs. W.R. and Ida Browne

After completing her secondary education at Fort Street Girls' High School she entered Sydney University in the faculty of Science in 1918. Her mind must have already been fully directed towards a career in Geology, having topped the State in the 1917 Leaving Certificate exam in this subject and with supporting honours in Mathematics and Botany. Her University academic record bore out this intention with a series of High Distinction and Prizes, and in March, 1922 she graduated with First Class Honours, the University Medal for Geology-Mineralogy and the Deas Thomson Scholarship, gaining the awards over the other First Class honours winner, H.G. Raggatt. In earlier years she had equalled or beaten such worthy candidates as G.D. Osborne and T.L. Willan.

Her interests at this time were clearly in the petrological-mineralogical field with field mapping of only slightly less interest, while she appears not to have taken the Palaeontological sections available in Geology III. She was awarded a Science Research Scholarship on graduation but resigned in April, 1922 to become a demonstrator in the department replacing another woman graduate, Dorothy (Dip) Powell. She retained this position till early in 1927 when she accepted a Linnean MacLeay Fellowship in Geology. While a demonstrator she had published a paper on minerals at Broken Hill and three papers on the South Coast geology which was claiming her attention. The years of her MacLeay Fellowship enabled her to give full attention to this little known area of the state which was traversed only by rough bush tracks masquerading as highways. During this period she published seven papers, several quite lengthy, on various aspects of South Coast Geology. The regional stratigraphy and the igneous bodies such as Mt. Dromedary and Milton were particularly dealt with. Her thesis 'The Geology of the South Coast of New South Wales with special reference to the origin and relationships of the igneous rocks' gained her the award of D.Sc. in 1932. At that time she was only the second woman to achieve such a distinction at the University.

In October, 1934 W.S. Dun, who had lectured part-time in Palaeontology at Sydney University for many years, died. Ida Brown had become a Demonstrator again in March of that year and although inexperienced in this branch of geology, she took over the task of mastering this new field and teaching in it. In March, 1935 she was appointed Assistant Lecturer in Palaeontology, to become successively Lecturer (1940) and Senior Lecturer (1945) resigning in August, 1950.

It is characteristic of Ida Brown that she published only two items between 1934 and 1940, one a note (based on her earlier work) in an Agricultural paper, the other with Germaine Joplin on the fossiliferous Upper Devonian rocks at Mt. Lambie. Her time was devoted to studying palaeontology and not till she felt she had this subject firmly understood did she publish any research in this field. She had found an area of great interest, rich in mapping problems and fossils, in the Yass region, and this was to hold her attention for the next thirty years.

In 1940 her first palaeontological paper appeared (a short note in fact), and eleven more on various fauna appeared in due course. The palaeontological papers are interspersed between papers dealing with stratigraphy and structure, mainly of the Yass region. These stratigraphic papers complete with large, detailed maps epitomize her love for field work and will, I feel, remain her most enduring geological memorial. In 1949 she married William Rowan Browne, long-time Reader in the Department of Geology at Sydney University. Following Browne's retirement in 1949 they enjoyed more than twenty years together in the field she acting as chauffeur and general guardian to the still active older geologist, specially on their long summer trips to the Kosciusko region.

In this period W.R. Browne produced more than forty research papers and articles, Ida Browne ten including some of her major works. The roles of assistant and guardian were reversed during the last years when Ida Browne was afflicted by a slow, paralysing illness which kept her virtually bed ridden. Despite his age W.R. Browne maintained much of his vigour and this he devoted to caring for Ida and easing her pain. His sudden

death late in 1975 meant a lonely last year for Dr. Ida. Almost all her papers were published by either the Royal Society or the Linnean Society of New South Wales, and to both of these she gave her active interest. She was President of the Royal Society in 1953-54 and served for many years on its Council.

In 1945 she presided over the Linnean Society and was also a long-term Councillor of this body. The libraries of the Australian Museum and Wollongong University both benefited from her generous donation of books. One of her last acts was to approve the establishment of a W.R.Browne medal by the Geological Society of Australia. Ida Browne published few papers in association with other workers (one with W.R. Browne, and three with other women geologists). Only two papers were published overseas, one being a joint publication. These two facts again are characteristic of her. She was happy to remain within the ambits of local science. Although aware of the literature and the world beyond she was content to apply her knowledge to local problems. Furthermore, she was content to solve them essentially unaided.

She belongs to an interesting period of the development of Australian Science during which a number of dedicated women quietly but firmly established themselves in fields which had been largely dominated by men. For this there is no doubt they owe some thanks to Edgeworth David and his wife but most of the effort was their own. Always a dignified and stately lady, Dr. Ida will be remembered for her precise lectures and her unfailing courtesy. Her accurate work in the field will continue to be quoted long into the future. That is the memorial she would have appreciated.

David Branagan

Keith Edward Bullen

On 23rd September, 1976 a most distinguished member of the Royal Society of N.S.W., Professor Keith Bullen, died in Auckland, New Zealand,while visiting relatives.

Keith Edward Bullen was born in Auckland on 29 June, 1906. After gaining a B.Sc. degree in physics and an M.A. (1st Class Honours) degree in mathematics, in 1927 he was appointed a Lecturer in mathematics at Auckland University College. From 1931 to 1933 he attended St. John's College, Cambridge, England, winning the Strathcona Exhibition. He worked with Sir Harold Jeffreys on the monumental task of constructing tables of travel times of seismic waves within the earth. The tables of the time were accurate to about one minute. The Jeffreys-Bullen tables are accurate to one or two seconds and are still, 30 years later, used for the location of earthquakes by the International Seismological Centre and the U.S. Geological Survey. The particular problem that Sir Harold Jeffreys set Keith Bullen was to work out the effect of the earth's flattening on the travel times of seismic waves within it. The results of this work are clearly and logically set out in the Geophysical Supplement of the Monthly Notices of the Royal Astronomical Society of May, 1937.

These so-called ellipticity corrections are not much used nowadays because, as they are only of about half a second, they are smaller than the variations of travel times of seismic waves caused by the differences of continental and oceanic crust near the earth's surface (two seconds). However, to estimate the ellipticity corrections, Keith Bullen had to study surfaces of equal density within the earth. Knowledge of density within the earth at that time was extremely vague. Keith Bullen integrated the Adams-Williamson equation from the bottom of the earth's crust to the earth's centre, and, after some disappointments, obtained results consistent with the earth's moment of inertia.

Keith Bullen was a lecturer at Hull University College in England in 1933. After this he returned to Auckland University College. On 15 May, 1935 he married Florence M. Pressley. In the later 1930's he produced a number of papers on New Zealand earthquakes, travel times of seismic waves, density within the earth, and on the crustal structure of New Zealand and the Pacific Ocean. I have reprints of 20 of these papers by me now as I write.

From 1940 to 1945 Keith Bullen was Senior Lecturer in Mathematics at the University of Melbourne. From 1946 tor 25 years until his retirement he was Professor of Applied Mathematics at the University of Sydney. In 1949 he received the Lyall Medal. In 1952 he received the Hector Medal in New Zealand. In 1953 he received the Walter Burfitt Prize of the Royal Society of N.S.W. Keith Bullen has left us three clear, logical and carefully written books on mechanics, seismology and the earth's density, as well as two less important books and a set of printed notes used at the International Institute of Seismology and Earthquake Engineering in Tokyo. When I look back at a deceased person's life I find myself concerned, not only about his discoveries, his awards and his publications, but also about his honesty, his dedication and the care with which he prepared lectures for the students who studied the courses he taught. Keith Bullen was well known at the University of Sydney for his honest, logical and clear lectures. Since he practised what he preached, a sentence from his Presidential Address to Section A of the Australian and New Zealand Association for the Advancement of Science in 1951 should go into his obituary: "In a world in which so little is done with meticulous care to detail, in which so relatively few are prepared to work with concentration

over long hours, or to look at problems with an honest impartiality, the magnificent work of the natural scientist stands out."

While at the University of Sydney, Keith Bullen was associated with three important and interesting research results. First, in 1946, he predicted from the sharp increase in the velocity of P waves at the earth's inner core boundary, that the inner core was solid. Second, the late Fr Burke-Gaffney, here at Riverview Observatory, colleceed seismic readings of four hydrogen bombs detonated in 1954. Keith Bullen estimated the times of the explosions to within 0.7, 0.4, 0.1 and 0.0 seconds respectively. The U.S. Atomic Energy Commission realized that that it was pointless to try to keep the times of large underground explosions secret, and has since released the times and locations of them all. These times and locations have been of great assistance to studies of the interior of the earth. Third, in 1952 H. Benioff in southern California observed what he thought were oscillations of the whole earth, with a period of approximately 54 minutes. Benioff requested C.L. Pekeris, a mathematician from Israel, to calculate the periods of oscillation of the whole earth. To do this Pekeris had to use models of the earth which incorporated values of the density and incompressibility found by Keith Bullen. Keith Bullen was delighted when these models were confirmed by observations of spherical oscillations from the Chilean earthquakes in 1960.

Keith Bullen received the Bicentennial Medal of Columbia University in 1954. He was President of the International Association of Seismology and the Physics of the Earth's Interior from 1955 to 1957. In 1957 he wss the Australian delegate at a most interesting conference in Washington on rockets and artificial satellites. In the course of the conference Sp-tnik 1 moved overhead.

In 1959 he was Vice-President of the Scientific Committee for Antarctic Research of the International Council of Scientific Unions (SCAR). He wrote:

"Ostensibly all the problems of SCAR were purely scientific ones, but for a long time there was a steady political undercurrent from the existence of several groups among the 12 nations represented on SCAR. The first group included countries like the United Kingdom, Australia, France and Norway which had mdde substantial claims of Antarctic territory. The second group included Argentina and Chile which also made claims, but claims incompatible with those of Britain. The United States and the U.S.S.R. constituted two further groups which, while not wholly in accord with each other, had this in common that they declined to recognize the claims of any other country, and in fact asserted the rights of both to carry out scientific investigations wherever they chose in Antarctica.

"In the early days of SCAR, one could never be quite sure whether an apparently innocent scientific proposal contained a significant political implication, and once again I learned how far scientists had moved from the old ivory-tower days. It appears that the labours of the SCAR scientists were not, however, in vain, and that they made an impact on governments, leading to the International Antarctic Treaty of 1959, which most people now seem to think is quite a good thing."

Keith Bullen wrote these paragraphs in 1964. In 1961 he received the William Bowie Medal of the American Geophysical Union. In 1963 he received the Day Gold Medal of the Geological Society of America. In 1965 he received the Research Medal of the Royal Society of Victoria. From 1963 to 1967 he was Vice-President of the International Union of Geodesy and Geophysics. He was elected to the Pontifical Academy of Science in 1968. He received the Gold Medal of the Royal Astronomical Society and became an Honorary Fellow of the Royal Society of New South Wales in 1974. He was a Fellow of the Royal Society, a Fellow of the Australian Academy of Science, a Foreign Associate of the U.S. National Academy of Sciences, a Fellow of the American Geophysical Union, a Foreign Honorary Member of the American Academy of Arts and Science, a Foreign and Commonwealth Member of the Geological Society of London, an Honorary Fellow of the Royal Society of New Zealand, and he received the Sc.D. degree from the University of Cambridge.

It only remains for me to say that Keith Bullen was respected and liked by all who worked with him, and to congratulate his widow, son and daughter on belonging to the family of so fine a man.

Lawrence A. Drake

Ernest Ritchie

The sudden death of Ernest Ritchie, Professor of Organic Chemistry in the University of Sydney, at his home on 9th April, 1976, has deeply saddened colleagues and friends throughout Australia and beyond. He was a man of great honesty, sincerity and kindliness who was universally admired and respected. There is now everywhere a profound sense of shock that he is no longer with us, which we share with his wife, Maisie, and family, Susan, Robert and Ian.

Ern Ritchie was born on 11th February, 1917, and grew up in the Eastern Suburbs district of Sydney. He attended Woollahra Superior Public School, Randwick Boys' Intermediate High School, and finally Sydney Boys' High School. With the help of a Public Exhibition Ritchie entered the Faculty of Science, Sydney University, in 1933 and as a result of a strong impression made by the then Senior Lecturer, Dr. Francis Lions, he embarked on his career in organic chemistry, graduating B.Sc. (HI) in 1937 and M.Sc. in 1939. Ritchie remained at the University, becoming Assistant Lecturer (1941), Senior Lecturer (1946), and Reader in Organic Chemistry (1961). In 1967 Ritchie was appointed to a Chair of Organic Chemistry and on the retirement of C.W.S. Shoppee he became head of the Department. During 1971-1973 he was Head of the School of Chemistry, following the retirement of R.J.W. Le Fevre.

It is perhaps difficult to gauge the full measure of the man's achievement and contributions, such was his modesty and lack of desire to seek special recognition. He simply loved doing Organic Chemistry and seeing the subject flourish. His name is a by-word amongst former students of chemistry of the past 30 years, such was the quality of his lecturing. In research, some 60 students have gained higher degrees under his guidance: four now hold University Chairs, and many others have risen to senior industrial and academic positions, including 6 readers and associate professors.

Ritchie's research interests were initially in the field of synthetic heterocyclic chemistry but when after World War II CSIRO initiated the Australian Phytochemical Survey the main thrust of his research effort developed, broadly on the chemistry of natural products of the Australian flora. Stemming from this, a total of over 150 research papers and several monographs have been published over a period of 30 years. The degree of D.Sc. was conferred on Ritchie in 1954 by the University of Sydney particularly for his pioneering work in the biogenetic theory of the plant alkaloids. However, his research interests were to become much broader than this: sizeable and highly significant contributions were also made in most major areas of natural product chemistry. Collaborative efforts on problems of biological importance were especially satisfying, the most recent contribution being the isolation and identification of the toxic substances responsible for St. George disease in cattle.

Recognition of Ritchie's work came early. He was the first recipient, in 1948, of the Edgeworth David Medal of the Royal Society of New South Wales, and in 1963 he was awarded the H.G. Smith Medal by the Royal Australian Chemical Institute. Election to the Australian Academy of Science came in 1963.

A member of the Royal Society of New South Wales since 1939, he contributed 19 papers to the Journal and Proceedings.

Ritchie had a dry sense of humour and he could always take heart from the lighter side of a situation. He excelled in the art of understatement in the best Australian tradition. It was these qualities together with his fund of unfailing cheerfulness, warmth and enthusiasm which endeared him to his many friends. His untimely departure is a source of great sadness to them.

During the year ended 31st March, 1977 the following changes in membership of the Society were effected.

ELECTION TO HONORARY MEMBERSHIP

CAREY, Professor Samuel Warren, D.Sc., Dept. of Geology, University of Tasmania, Hobart, Tasm., 7000.

ELKIN, Emeritus Professor Adolphus Peter, C.M.G., Ph.D., 15 Norwood Ave., Lindfield, N.S.W., 2070.

PRICE, Sir Robert, 314 Albert Street, East Melbourne, Vict. 3002.

ELECTION TO LIFE MEMBERSHIP

MORT, Francis George Arnot
ROUNTREE, Phyllis Margaret, D.Sc.

ELECTION TO MEMBERSHIP

AITKEN, Janet Mary, B.Sc., M. Phil., 82 Mimosa Road, Greenacre, N.S.W., 2190.

FRAZER, Geoffrey Leon, 4 Bradley Drive, Carlingford, N.S.W., 2118.

HARDY, Clarence James, B.Sc., Ph.D., D.Sc., 12 Brassie Street, North Bondi, N.S.W., 2026.

HENRY, Hugh Moore, B.A.(Syd.), B.A.(Macq.), Dip. Ed.(Syd.), 11 Fifth Ave., Cremorne, N.S.W., 2090.

McANDREW, John, B.Sc., Ph.D., Division of Mineral Physics, C.S.I.R.O., P.O. Box 136, North Ryde, N.S.W., 2113.

MARTIN, Helene A., Ph.D., School of Botany, University of N.S.W., Kensington, N.S.W., 2033.

MIKULSKI, John, B.Sc.(Hons.), 56 Kyooma Street, Tamworth, N.S.W., 2340.

MORGAN, Thomas Leslie, B.Sc., c/- Sydney Observatory, Sydney, N.S.W., 2000.

ROY, Peter Stanton, B.Sc., Ph.D., 16 Hodgson Ave., Cremorne, N.S.W., 2090.

STUBBS-RACE, Michael Anthony, 35 Dress Circle Road, Avalon, N.S.W., 2107.

WALLACE, Harry Lachlan, B.E.(Mech.), 25 York St., Beecroft, N.S.W., 2119.

WILSON, Mark Hume, B.A., Dip.Ed., 10 Neil Street, Epping, N.S.W., 2121.

ELECTION TO ASSOCIATE MEMBERSHIP

BALAREZO, Oscar Walter Mendoza, 4/16 Oxley St., Glebe, N.S.W., 2037.

BILLS, Ross Maynard, c/- St. Andrews College, University of Sydney, Newtown, N.S.W., 2042.

FINN, Anne Marie, 1A Grove Ave., Penshurst, N.S.W. 2222.

JACKSON, Caroline Margaret (address unknown)

McMINN, Andrew, 80 Kissing Point Road, Turramurra, N.S.W., 2074.

MOORE, Peter Stanley, B.Sc.(Hons.), St. Ann's College, 187 Brougham Place, North Adelaide, S.A., 5006.

SKRINJARIC, Marica Catherine, 6 Hereford Street, Botany, N.S.W., 2019.

SLADE, Rhonda Maree, 29 Irvine Street, Kingsford, N.S.W., 2032.

THOMPSON, Denise Mary, 82 Awaba St., Mosman, N.S.W., 2088.

RESIGNATION OF MEMBERS

Richard Hugh McDonald Arnot
David Somerset Bridges
Gurij Gordijew
Charles Mark Groden
Robert John Gunthorpe
Edith Lack
John Francis Lovering
Allan James George McGillivray
Dirk Cornelius Van Dijk
Neil Tolmie McRae Yeates

RESIGNATION OF ASSOCIATE MEMBERS

Allison Joan Baggs
Roderic Gill

OBITUARY

Ida Alison BROWNE (1935; Pres. 1953; Life Member 1974) (deceased 21.10.76)

Betty Brunsdon BOWEN (1974) (deceased 3.7.76)

Keith Edward BULLEN (1946; Honorary Member 1974) (deceased 23.9.76)

Cyril Lloyd COOK (1968) (deceased 16.1.77)

Adrian Noel OLD (1947) (deceased 17.11.76)

Ernest RITCHIE (1939; Life Member) (deceased 9.4.76)

Arthur Bache WALKOM (1919; President 1943; Life Member) (deceased 2.7.76)

Journal and Proceedings, Royal Society of New South Wales, Vol. 110, pp. 81-86, 1977

Occultations Observed at Sydney Observatory During 1974–1976

D. S. KING AND K. P. SIMS

ABSTRACT. This paper presents the results of occultations observed with the 29 cm telescope during the years 1974-1976.

The following observations of occultations were made at Sydney Observatory with the 29 cm telescope. A tapping key was used to record the times on a chronograph. The reduction elements were computed by the method given in the occultation supplement to the *Nautical Almanac* for 1938 and the reduction completed by the method given there. Since the observed times were in terms of co-ordinated time (U.T.C.), a correction of +0.01218 hours (=43.85 seconds) was applied to these observed times to convert them to ephemeris time with which *The Astronomical Ephemeris for 1974* was entered to obtain the position and parallax of the Moon in terms of the FK4 co-ordinate system.

Corrections of +0.01244 hour (=44.8 seconds) and +0.01269 hour (=45.7 seconds) were similarly applied to the observed times in 1975 and 1976 respectively before entering *The Astronomical Ephemeris for 1975* and *The Astronomical Ephemeris for 1976* to obtain the position and parallax of the Moon in terms of the FK4 co-ordinate system.

The apparent places of the stars for the 1974 occultations were provided by H.M. Nautical Almanac Office. For the 1975 and 1976 occultations, the apparent places of the occulted stars were computed from their positions in the *Catalogue of 3539 Zodiacal Stars for Equinox 1950.0* and the *Smithsonian Astrophysical Observatory Star Catalogue* using a Diehl Alphatronic computer.

Table 1 gives the observational material. The serial numbers follow on from those of the previous report (Sims, 1973). The observers were D. S. King (K), T. L. Morgan (M), W. H. Robertson (R), K. P. Sims (S) and H. W. Wood (W). Except for occultations 788, 818, 826 which were reappearances at the dark limb, the phase observed was disappearance at the dark limb. Table 2 gives the results of the reductions which were carried out in duplicate. The Z.C. or S.A.O. numbers given in Table 1 are from the *Catalogue of 3539 Zodiacal Stars for Equinox 1950.0* (Robertson 1940) and the *Smithsonian Astrophysical Observatory Star Catalogue.*

REFERENCES

Robertson, A.J., 1940 *Astronomical Papers of the American Ephemeris, 10 (2)*

Sims, K.P., 1973 *J. Proc. Roy. Soc. N.S.W. 108, 1 Sydney Observatory Papers No. 73*

TABLE 1

Serial No.	S.A.O. or Z.C. No.	Mag.	Date	U.T.C.	Observer
770	0107	8.9	1974 Jan. 29	9 53 33.1	R
771	1033	6.8	1974 Feb. 4	10 31 26.3	S
772	092894	9.0	1974 Feb. 27	9 31 07.3	R
773	092896	8.6	1974 Feb. 27	9 36 02.2	R
774	076516	8.3	1974 Mar. 1	9 04 53.0	R
775	0960	6.6	1974 Mar. 3	9 16 32.5	W
776	0962	7.0	1974 Mar. 3	9 25 54.8	W
777	0964	7.0	1974 Mar. 3	9 37 06.8	W
778	1123	7.2	1974 Mar. 4	12 06 10.8	W
779	1127	5.9	1974 Mar. 4	13 02 06.7	W
780	097753	6.8	1974 Mar. 5	9 23 54.0	R
781	0594	6.9	1974 Mar. 28	9 20 42.1	W
782	076389	7.8	1974 Mar. 28	9 20 51.2	W
783	076869	8.6	1974 Mar. 29	8 18 24.8	R
784	076885	8.3	1974 Mar. 29	8 50 22.7	R
785	076913	8.6	1974 Mar. 29	10 00 52.4	R
786	076915	8.4	1974 Mar. 29	10 04 49.3	R
787	077851	7.9	1974 Mar. 30	8 41 42.5	W
788	145934	8.5	1974 Apr. 17	18 33 18.2	R
789	117890	7.9	1974 Apr. 30	12 46 39.3	S
790	138052	8.2	1974 May. 29	10 17 23.6	R

TABLE 1 (cont.)

Serial No.	S.A.O. or Z.C. No.	Mag.	Date	U.T.C.	Observer
791	138556	7.2	1974 May. 30	10 02 22.3	W
792	138592	7.8	1974 May. 30	12 41 17.4	S
793	1845	6.5	1974 May. 31	8 10 25.2	R
794	118054	8.8	1974 June 24	7 59 17.0	S
795	118059	8.7	1974 June 24	8 22 23.0	S
796	118073	8.6	1974 June 24	8 53 53.5	S
797	1705	7.5	1974 June 26	7 32 50.7	S
798	138911	8.0	1974 June 27	9 46 30.5	W
799	138935	7.6	1974 June 27	11 40 24.5	R
800	138945	8.6	1974 June 27	12 42 45.8	R
801	118373	8.5	1974 July 22	7 53 24.9	R
802	1778	7.1	1974 July 24	8 29 34.1	S
803	138552	8.7	1974 Aug. 20	8 53 23.7	R
804	1930	5.6	1974 Sep. 18	8 03 25.5	S
805	185128	8.6	1974 Sep. 22	9 06 15.9) 9 06 20.5)	R
806	185127	8.8	1974 Sep. 22	9 09 47.6	R
807	185697	8.3	1974 Oct. 20	9 03 50.2	R
808	185721	8.7	1974 Oct. 20	9 39 22.8	R
809	2968	6.2	1974 Oct. 23	11 03 42.0) 11 03 44.2)	S
810	2969	3.2	1974 Oct. 23	11 12 36.4	S
811	163486	9.3	1974 Oct. 23	11 19 23.2	S
312	3277	7.8	1974 Nov. 22	10 04 37.6	S
813	0233	6.2	1975 Jan. 20	9 53 35.4	S
814	0739	7.4	1975 Feb. 20	10 59 24.5	R
815	1142	7.8	1975 Mar. 22	10 42 31.0	R
816	097018	8.0	1975 Mar. 22	11 20 01.4	R
817	097072	7.9	1975 Mar. 22	12 42 44.4	R
818	162239	7.4	1975 Apr. 3	17 26 21.0	R
819	0792	5.1	1975 Apr. 16	9 21 13.9	R
820	0905	6.7	1975 May. 14	8 04 13.0	M
821	097338	7.5	1975 May. 16	7 36 45.4	M
822	117890	7.9	1975 May. 18	7 43 29.4	R
823	1440	6.7	1975 May. 18	9 05 20.0	R
824	117923	8.3	1975 May. 18	10 07 08.2	R
825	1688	6.3	1975 May. 20	11 14 51.6	R
826	092548	7.1	1975 June 5	19 29 42.2	R
827	139025	7.8	1975 July 15	7 23 30.7	R
828	1853	4.9	1975 July 15	8 23 26.7	R
829	139037	8.3	1975 July 15	8 26 57.2	R
830	2111	7.0	1975 July 17	9 57 39.3	R
831	2241	5.0	1975 July 18	7 52 26.9	S
832	1815	4.8	1975 Aug. 11	9 03 45.6	S
833	158085	7.3	1975 Aug. 12	11 45 53.5	M
834	158631	8.8	1975 Aug. 13	9 21 13.2	S
835	158636	9.0	1975 Aug. 13	9 50 01.8	S
836	158682	8.8	1975 Aug. 13	11 54 42.0	M
837	159286	8.2	1975 Aug. 14	8 39 55.5	R
838	159309	8.0	1975 Aug. 14	10 07 07.0	R
839	2233	5.5	1975 Aug. 14	14 10 03.2	M
840	2498	4.5	1975 Aug. 16	7 47 18.7	R
841	157813	8.7	1975 Sep. 8	9 12 48.8	S
842	1900	7.2	1975 Sep. 8	9 18 21.0	S
843	2173	7.0	1975 Sep. 10	9 38 00.2	S
844	2182	6.3	1975 Sep. 10	10 53 07.7	M
845	159818	8.6	1975 Sep. 11	12 12 36.5	M
846	2338	6.6	1975 Sep. 11	12 48 24.6	M
847	185116	7.1	1975 Sep. 12	11 03 25.1	S
848	2465	7.4	1975 Sep. 12	11 16 32.5	S
849	162748	7.4	1975 Oct. 12	8 53 02.7	R
850	2975	7.0	1975 Oct. 13	8 36 58.3	R
851	163557	8.0	1975 Oct. 13	10 01 19.4	R
852	163571	8.0	1975 Oct. 13	10 15 04.3	R
853	163570	7.9	1975 Oct. 13	10 23 00.9	R
854	3125	6.9	1975 Oct. 14	15 29 59.8	M
855	185325	8.9	1975 Nov. 6	9 29 09.0	R
856	185337	8.3	1975 Nov. 6	9 47 12.3	R
857	145407	8.6	1975 Dec. 8	9 33 58.7	M
858	145406	7.9	1975 Dec. 8	9 35 58.3	M

Serial No.	S.A.O. or Z.C. No.	Mag.	Date	U.T.C.	Observer
859	145412	9.3	1975 Dec. 8	10 04 15.3	M
860	145434	8.7	1975 Dec. 8	11 06 54.7	M
861	3151	9.0	1975 Dec. 8	11 11 04.2	M
862	3464	7.1	1976 Jan. 7	11 39 23.1	R
863	0092	8.7	1976 Feb. 5	9 46 40.6	R
864	109398	8.8	1976 Feb. 5	10 03 59.7	R
865	1158	5.2	1976 Feb. 13	8 58 19.4	K
866	095544	7.9	1976 Mar. 10	10 42 55.6	R
867	0971	7.3	1976 Mar. 10	11 19 32.1	M
868	077821	8.8	1976 Apr. 6	9 01 23.5	R
869	077828	8.4	1976 Apr. 6	9 12 35.6	R
870	077840	8.8	1976 Apr. 6	9 20 25.0	R
871	077850	8.4	1976 Apr. 6	9 39 04.1	R
872	0915	4.7	1976 Apr. 6	11 03 26.1	R
873	077515	8.3	1976 May. 3	8 30 55.8	M
874	0873	7.9	1976 May. 3	9 08 13.5	M
875	077547	7.2	1976 May. 3	9 09 27.2	M
876	095939	8.5	1976 May. 4	8 26 59.6	M
877	095945	9.2	1976 May. 4	8 45 25.9	M
878	095965	8.1	1976 May. 4	8 58 48.1	M
879	095980	8.5	1976 May. 4	9 23 50.6	R
880	097009	8.8	1976 May. 5	8 59 56.4	S
881	097004	8.9	1976 May. 5	9 09 58.3	S
882	097030	8.1	1976 May. 5	9 58 59.0	S
883	097032	9.0	1976 May. 5	10 10 23.0	S
884	097056	9.1	1976 May. 5	10 24 03.2	S
885	097083	7.6	1976 May. 5	11 10 05.0	S
886	1271	5.9	1976 May. 6	10 08 51.5	S
887	098491	7.9	1976 May. 7	8 04 16.2	M
888	098487	8.3	1976 May. 7	8 08 22.8	M
889	098494	8.9	1976 May. 7	8 22 27.0	M
890	098344	8.5	1976 June 3	8 23 51.4	R
891	098341	8.7	1976 June 3	8 24 50.0	R
892	1457	6.7	1976 June 4	7 10 20.8	M
893	118059	8.7	1976 June 4	10 47 09.1	M
894	118073	8.6	1976 June 4	11 22 29.9	M
895	1843	6.9	1976 June 7	14 57 45.8	R
896	2117	5.3	1976 June 9	17 19 16.8	R
897	118408	8.6	1976 July 2	8 45 22.6	K
898	1564	6.6	1976 July 2	11 08 54.3	K
899	1792	7.1	1976 July 4	11 56 26.4	R
900	138821	8.7	1976 July 4	12 05 27.6	R
901	139285	8.1	1976 July 5	9 49 39.3	M
902	158546	7.4	1976 July 6	13 23 20.9	K
903	2331	6.4	1976 July 8	7 53 05.4	R
904	2345	6.9	1976 July 8	10 40 21.3	R
905	2658	5.4	1976 July 10	10 44 44.0	R
906	118767	8.8	1976 July 30	8 48 55.4	M
907	118783	7.6	1976 July 30	9 34 23.0	M
908	158173	8.8	1976 Aug. 29	9 05 51.1	S
909	158175	8.6	1976 Aug. 29	9 23 47.4	S
910	2361	4.8	1976 Sep. 28	8 38 50.9	S
911	2368	8.2	1976 Sep. 28	10 16 59.5	S
912	159953	8.9	1976 Sep. 28	10 23 04.7	S
913	3477	6.6	1976 Oct. 6	10 30 39.7	K
914	162197	9.0	1976 Oct. 28	9 09 43.3	S
915	2789	7.3	1976 Oct. 28	9 35 30.1	S
916	162251	8.4	1976 Oct. 28	10 33 17.7	S
917	2722	7.1	1976 Nov. 24	10 21 23.5	K
918	128469	8.0	1976 Nov. 30	10 56 09.0	R
919	146372	8.3	1976 Dec. 26	11 08 56.7	R
920	3494	4.6	1976 Dec. 27	11 59 30.5	R
921	0413	6.8	1976 Dec. 31	10 48 29.0	S

TABLE 2

Serial No.	Lunation No.	p	q	p^2	pq	q^2	$\Delta\sigma$	$p\Delta\sigma$	$q\Delta\sigma$	Coefficient of $\Delta\alpha$	Coefficient of $\Delta\delta$
770	632	+ 41	+ 91	17	+ 38	83	- 0.4	- 0.2	- 0.3	+ 0.8	+ 1.00
771	632	+ 99	+ 13	98	+ 13	2	- 0.3	- 0.3	0.0	+13.9	- 0.03
772	633	+ 91	+ 41	83	+ 37	17	- 0.3	- 0.3	- 0.1	+11.0	+ 0.64
773	633	+ 70	- 71	49	- 50	51	- 0.5	- 0.4	+ 0.4	+12.3	- 0.50
774	633	+ 57	- 82	32	- 47	68	+ 1.2	+ 0.7	- 1.0	+ 8.9	- 0.77
775	633	+ 80	+ 59	65	+ 48	35	- 1.0	- 0.8	- 0.6	+12.0	+ 0.50
776	633	+ 99	+ 16	98	+ 16	3	+ 0.9	+ 0.9	+ 0.1	+13.8	+ 0.05
777	633	+ 85	- 52	73	- 45	27	+ 1.4	+ 1.2	- 0.7	+10.9	- 0.62
778	633	+ 95	- 30	90	- 29	9	- 2.1	- 2.0	+ 0.6	+12.1	- 0.51
779	633	+ 79	- 61	62	- 49	38	+ 0.4	+ 0.3	- 0.2	+ 8.9	- 0.78
780	633	+ 83	+ 56	69	+ 47	32	+ 0.8	+ 0.6	+ 0.4	+13.7	+ 0.30
781	634	+ 97	+ 24	95	+ 23	6	+ 0.5	+ 0.5	+ 0.1	+13.0	+ 0.35
782	634	+ 97	+ 23	95	+ 23	5	+ 0.8	+ 0.8	+ 0.2	+13.0	+ 0.34
783	634	+ 40	- 92	16	- 35	84	- 1.5	- 0.6	+ 1.4	+ 5.7	- 0.91
784	634	+ 93	+ 36	87	+ 34	13	- 0.1	- 0.1	0.0	+12.8	+ 0.38
785	634	+ 87	- 50	76	- 43	25	+ 0.4	+ 0.4	- 0.2	+12.1	- 0.49
786	634	+ 89	+ 46	79	+ 41	21	- 0.6	- 0.5	- 0.3	+12.2	+ 0.47
787	634	+ 81	+ 58	66	+ 47	34	- 0.7	- 0.6	- 0.4	+11.9	+ 0.51
788	634	- 54	+ 84	29	- 45	71	- 1.3	+ 0.7	- 1.1	-12.2	+ 0.57
789	635	+100	- 3	100	- 3	0	+ 3.6	+ 3.6	- 0.1	+13.7	- 0.40
790	636	+ 70	- 72	48	- 50	52	+ 2.1	+ 1.5	- 1.5	+ 5.4	- 0.94
791	636	+ 94	+ 34	88	+ 32	12	- 1.1	- 1.0	- 0.4	+14.9	- 0.04
792	636	+ 99	+ 13	98	+ 13	2	- 1.5	- 1.5	- 0.2	+14.4	- 0.25
793	636	+ 51	- 86	26	- 43	74	+ 0.8	+ 0.4	- 0.7	+ 2.6	- 0.99
794	637	+ 97	- 24	94	- 23	6	+ 0.3	+ 0.2	- 0.1	+12.1	- 0.58
795	637	+ 91	- 42	83	- 38	17	+ 0.8	+ 0.8	- 0.4	+10.2	- 0.73
796	637	+ 97	+ 26	93	+ 25	7	- 0.3	- 0.3	- 0.1	+14.8	- 0.12
797	637	+100	+ 6	100	+ 6	0	- 0.2	- 0.2	0.0	+14.1	- 0.33
798	637	+ 85	+ 53	72	+ 45	28	- 0.2	- 0.2	- 0.1	+14.5	+ 0.19
799	637	+ 99	- 13	98	- 13	2	+ 0.2	+ 0.2	0.0	+13.0	- 0.48
800	637	+ 21	- 98	5	- 21	96	+ 1.9	+ 0.4	- 1.9	- 2.2	- 0.99
801	638	+ 70	- 71	49	- 50	51	+ 1.4	+ 1.0	- 1.0	+ 5.6	- 0.93
802	638	+ 54	+ 84	29	+ 45	71	+ 0.7	+ 0.4	+ 0.6	+12.1	+ 0.58
803	639	+ 88	+ 47	78	+ 42	22	- 0.3	- 0.3	- 0.2	+14.8	+ 0.11
804	640	+ 32	+ 95	10	+ 30	90	- 0.6	- 0.2	- 0.6	+ 8.7	+ 0.80
805	640	+ 99	- 10	99	- 10	1	- 1.0	- 1.0	+ 0.1	+13.8	- 0.09
806	640	+ 86	+ 50	74	+ 43	25	- 3.0	- 2.6	- 1.5	+11.9	+ 0.50
807	641	+100	+ 4	99	+ 4	0	- 2.0	- 2.0	- 0.1	+13.8	+ 0.10
808	641	+ 96	+ 26	92	+ 25	7	- 2.7	- 2.6	- 0.7	+13.1	+ 0.32
809	641	+100	+ 5	99	+ 5	0	- 1.9	- 1.9	- 0.1	+13.6	+ 0.33
810	641	+100	- 4	100	- 4	0	- 0.6	- 0.6	0.0	+14.0	+ 0.24
811	641	+ 96	- 29	91	- 28	9	- 0.5	- 0.5	+ 0.1	+14.5	- 0.01
812	642	+ 92	+ 40	84	+ 37	16	- 1.1	- 1.0	- 0.4	+10.5	+ 0.71
813	644	+ 66	+ 75	44	+ 50	56	- 1.2	- 0.8	- 0.9	+ 5.9	+ 0.91
814	645	+ 99	- 15	98	- 15	2	- 1.0	- 1.0	+ 0.2	+13.8	- 0.12
815	646	+ 60	- 80	36	- 48	64	+ 0.7	+ 0.4	- 0.5	+ 5.9	- 0.91
816	646	+ 86	- 51	74	- 44	26	+ 1.0	+ 0.8	- 0.5	+10.5	- 0.68
817	646	+ 98	- 17	97	- 17	3	- 1.3	- 1.3	+ 0.2	+13.2	- 0.38
818	646	-100	+ 8	100	- 8	1	+ 0.9	- 0.9	+ 0.1	-14.1	- 0.09
819	647	+ 99	+ 11	99	+ 11	1	+ 1.3	+ 1.3	+ 0.2	+13.9	+ 0.10
820	648	+ 95	+ 31	90	+ 30	10	- 0.1	- 0.1	0.0	+13.6	+ 0.24
821	648	+ 42	- 91	18	- 38	83	+ 1.6	+ 0.7	- 1.4	+ 2.8	- 0.98
822	648	+ 49	+ 87	24	+ 43	76	- 0.2	- 0.1	- 0.2	+11.3	+ 0.65
823	648	+ 61	+ 79	37	+ 48	63	- 0.3	- 0.2	- 0.2	+12.5	+ 0.54
824	648	+ 75	+ 67	56	+ 50	45	+ 0.8	+ 0.6	+ 0.5	+13.8	+ 0.37
825	648	+ 98	+ 19	97	+ 18	4	+ 0.3	+ 0.3	+ 0.1	+14.7	- 0.18
826	648	- 91	+ 40	84	- 37	16	- 0.1	+ 0.1	- 0.1	-14.5	+ 0.12
827	650	+ 90	+ 44	81	+ 39	19	- 1.1	- 1.0	- 0.5	-14.7	+ 0.12
828	650	+ 67	- 75	44	- 50	56	+ 1.9	+ 1.3	- 1.4	+ 5.7	- 0.93
829	650	+ 70	+ 71	50	+ 50	50	- 0.1	- 0.1	- 0.1	+13.3	+ 0.44
830	650	+100	+ 8	99	+ 8	1	- 1.1	- 1.1	- 0.1	+14.2	- 0.14
831	650	+ 83	- 56	68	- 47	32	+ 0.8	+ 0.7	- 0.5	+10.4	- 0.68
832	651	+ 91	- 40	84	- 37	16	+ 0.4	+ 0.4	- 0.2	+10.8	- 0.69
833	651	+ 97	+ 26	93	+ 25	7	+ 0.3	+ 0.3	+ 0.1	+14.6	- 0.02
834	651	+ 99	- 13	98	- 13	2	- 0.3	- 0.3	0.0	+13.4	- 0.36
835	651	+ 97	- 23	95	- 23	5	+ 0.3	+ 0.3	- 0.1	+12.9	- 0.45
836	651	+ 99	- 13	98	- 13	2	+ 0.5	+ 0.5	- 0.1	+13.5	- 0.35
837	651	+ 61	+ 79	38	+ 48	62	- 1.2	- 0.8	- 1.0	+10.4	+ 0.68
838	651	+ 69	+ 73	47	+ 50	53	- 1.4	- 0.9	- 1.0	+11.2	+ 0.61

TABLE 2 (cont.)

Serial No.	Lunation No.	ρ	q	ρ^2	pq	q^2	Δσ	pΔσ	qΔσ	Coefficient of Δα	Coefficient of Δδ
839	651	+ 78	- 63	61	- 49	39	+ 1.2	+ 0.9	- 0.7	+ 9.6	- 0.73
840	651	+ 50	- 87	25	- 43	75	+ 0.7	+ 0.4	- 0.6	+ 7.0	- 0.87
841	652	+ 59	+ 81	35	+ 48	65	- 1.1	- 0.6	- 0.9	+11.9	+ 0.58
842	652	+ 22	+ 98	5	+ 21	95	- 1.1	- 0.2	- 1.0	+ 7.5	+ 0.86
843	652	+ 94	- 35	88	- 33	12	- 0.2	- 0.2	+ 0.1	+12.2	- 0.51
844	652	+ 29	+ 95	9	+ 28	91	- 1.3	- 0.4	- 1.2	+ 6.5	+ 0.89
845	652	+ 75	- 66	56	- 50	44	+ 1.0	+ 0.8	- 0.7	+ 9.7	- 0.73
846	652	+ 55	- 84	30	- 46	70	+ 1.1	+ 0.6	- 0.9	+ 6.7	- 0.88
847	652	+ 95	- 31	90	- 30	10	- 0.2	- 0.2	+ 0.1	+13.3	- 0.32
848	652	+ 86	+ 51	73	+ 44	26	- 2.2	- 1.9	- 1.1	+12.0	+ 0.51
849	653	+ 38	+ 92	14	+ 35	85	- 0.5	- 0.2	- 0.4	+ 2.7	+ 0.98
850	653	+ 68	- 74	46	- 50	54	- 0.4	- 0.2	+ 0.3	+12.3	- 0.53
851	653	+ 75	+ 66	56	+ 49	43	- 1.7	- 1.3	- 1.1	+ 8.0	+ 0.83
852	653	+ 74	- 67	55	- 50	46	+ 0.4	+ 0.3	- 0.3	+12.9	- 0.46
853	653	+ 88	+ 48	77	+ 42	23	- 2.2	- 1.9	- 1.0	+10.5	+ 0.69
854	653	+ 91	- 40	83	- 37	16	- 1.7	- 1.5	+ 0.7	+14.7	- 0.10
855	654	+ 98	+ 17	97	+ 17	3	- 0.4	- 0.4	- 0.1	+13.8	+ 0.19
856	654	+ 87	- 49	76	- 43	24	- 0.6	- 0.6	+ 0.3	+12.3	- 0.48
857	655	+ 77	- 64	59	- 49	41	+ 0.4	+ 0.3	- 0.3	+13.8	- 0.37
858	655	+ 96	+ 28	92	+ 27	8	- 0.6	- 0.6	- 0.2	+12.2	+ 0.57
859	655	+ 90	+ 44	80	+ 39	19	- 1.7	- 1.5	- 0.7	+10.6	+ 0.70
860	655	+ 90	+ 42	82	+ 38	18	- 1.9	- 1.7	- 0.8	+10.7	+ 0.69
861	655	+ 98	- 20	97	- 19	4	+ 2.5	+ 2.5	- 0.5	+14.7	+ 0.12
862	656	+ 96	+ 27	93	+ 26	7	- 0.8	- 0.8	- 0.2	+12.1	+ 0.59
863	657	+ 96	+ 28	92	+ 27	8	- 0.3	- 0.3	- 0.1	+12.1	+ 0.58
864	657	+ 43	+ 90	18	+ 39	81	- 0.6	- 0.3	- 0.5	+ 1.7	+ 0.99
865	657	+ 96	+ 28	92	+ 27	8	+ 0.2	+ 0.2	+ 0.1	+14.3	+ 0.08
866	658	+ 42	- 91	17	- 38	83	+ 1.8	+ 0.8	- 1.7	+ 4.7	- 0.95
867	658	+ 79	- 61	63	- 48	37	+ 0.4	+ 0.3	- 0.2	+10.4	- 0.68
868	659	+ 54	- 84	30	- 46	71	+ 1.1	+ 0.6	- 0.9	+ 7.0	- 0.87
869	659	+ 53	- 85	28	- 45	72	+ 0.9	+ 0.5	- 0.8	+ 6.7	- 0.88
870	659	+100	- 8	99	- 8	1	+ 0.7	+ 0.7	- 0.1	+14.0	- 0.14
871	659	+ 69	+ 72	47	+ 50	53	+ 0.1	+ 0.1	+ 0.1	+10.4	+ 0.68
872	659	+ 99	+ 13	99	+ 12	2	+ 0.8	+ 0.8	+ 0.1	+14.1	+ 0.06
873	660	+ 75	+ 66	56	+ 50	44	- 0.4	- 0.3	- 0.3	+10.9	+ 0.63
874	660	+ 88	- 47	78	- 41	22	- 0.1	- 0.1	0.0	+12.2	- 0.50
875	660	+100	- 3	100	- 3	0	- 1.2	- 1.2	0.0	+14.1	- 0.07
876	660	+ 94	- 35	87	- 33	12	- 1.1	- 1.1	+ 0.4	+12.6	- 0.46
877	660	+ 68	- 73	47	- 50	53	- 0.9	- 0.6	+ 0.7	+ 8.4	- 0.80
878	660	+ 99	+ 15	98	+ 14	2	+ 0.3	+ 0.3	0.0	+14.2	+ 0.03
879	660	+ 68	+ 74	46	+ 50	54	+ 0.7	+ 0.5	+ 0.5	+10.8	+ 0.65
880	660	+ 84	- 54	71	- 45	29	+ 1.0	+ 0.8	- 0.5	+10.5	- 0.69
881	660	+ 52	- 86	27	- 45	73	+ 1.9	+ 1.0	- 1.7	+ 5.0	- 0.94
882	660	+ 64	- 77	41	- 49	59	- 0.2	- 0.1	+ 0.1	+ 6.9	- 0.88
883	660	+ 45	- 90	20	- 40	80	+ 2.2	+ 1.0	- 1.9	+ 3.9	- 0.96
884	660	+ 57	+ 82	32	+ 47	67	- 0.6	- 0.3	- 0.5	+10.3	+ 0.70
885	660	+ 99	- 17	97	- 17	3	+ 0.7	+ 0.7	- 0.1	+13.4	- 0.36
886	660	+ 99	+ 14	98	+ 14	2	+ 0.3	+ 0.3	0.0	+14.5	- 0.11
887	660	+ 87	+ 49	76	+ 43	24	- 0.1	- 0.1	- 0.1	+14.4	+ 0.22
888	660	+ 94	- 35	87	- 33	12	- 1.3	- 1.2	+ 0.4	+11.7	- 0.61
889	660	+ 89	+ 45	80	+ 41	21	+ 2.0	+ 1.8	+ 0.9	+14.6	+ 0.17
890	661	+ 64	- 77	41	- 49	59	- 0.2	- 0.1	+ 0.1	+ 5.9	- 0.92
891	661	+ 51	- 86	26	- 44	74	+ 1.6	+ 0.8	- 1.4	+ 3.6	- 0.97
892	661	+ 64	- 77	41	- 49	59	+ 1.2	+ 0.8	- 0.9	+ 5.5	- 0.93
893	661	+ 97	- 23	95	- 22	5	+ 0.8	+ 0.8	- 0.2	+12.6	- 0.53
894	661	+ 92	+ 38	85	+ 35	15	- 0.6	- 0.5	- 0.2	+14.9	+ 0.07
895	661	+ 90	+ 43	81	+ 39	19	- 1.3	- 1.1	- 0.6	+14.7	+ 0.13
896	661	+ 65	- 76	42	- 50	58	+ 1.4	+ 0.9	- 1.1	+ 6.9	- 0.88
897	662	+ 98	- 20	96	- 20	4	+ 0.2	+ 0.2	0.0	+12.8	- 0.52
898	662	+ 94	- 34	87	- 32	12	- 3.3	- 3.1	+ 1.1	+11.5	- 0.64
899	662	+ 88	- 46	78	- 41	21	- 2.5	- 2.2	+ 1.2	+10.3	- 0.72
900	662	+ 93	- 37	86	- 35	14	- 1.4	- 1.3	+ 0.5	+11.3	- 0.65
901	662	+ 8	-100	1	- 8	100	+ 1.0	+ 0.1	- 1.0	- 3.2	- 0.98
902	662	+ 63	+ 77	40	+ 49	60	- 0.8	- 0.5	- 0.6	+11.6	+ 0.60
903	662	+ 80	+ 60	64	+ 48	36	- 1.5	- 1.2	- 0.9	+12.2	+ 0.51
904	662	+ 90	+ 43	81	+ 39	18	- 1.8	- 1.6	- 0.8	+13.3	+ 0.34
905	662	+ 90	+ 43	81	+ 39	19	- 1.7	- 1.5	- 0.7	+12.2	+ 0.51
906	663	+ 99	+ 11	99	+ 11	1	+ 0.1	+ 0.1	0.0	+14.6	- 0.23
907	663	+ 91	+ 42	82	+ 38	17	- 1.0	- 0.9	- 0.4	+14.9	+ 0.09

TABLE 2 (cont.)

Serial No.	Lunation No.	ρ	q	ρ^2	pq	q^2	Δσ	pΔσ	qΔσ	Coefficient of Δα	Coefficient of Δδ
908	664	+100	0	100	0	0	+ 0.7	+ 0.7	0.0	+14.1	- 0.27
909	664	+ 70	+ 72	48	+ 50	52	+ 0.4	+ 0.3	+ 0.3	+12.7	+ 0.50
910	665	+100	+ 7	99	+ 7	0	- 1.6	- 1.5	- 0.1	+14.2	- 0.01
911	665	+ 57	- 82	33	- 47	68	+ 0.6	+ 0.4	- 0.5	+ 7.1	- 0.86
912	665	+ 89	+ 45	79	+ 40	20	- 3.1	- 2.8	- 1.4	+13.1	+ 0.37
913	665	+ 99	- 17	97	- 17	3	+ 0.5	+ 0.5	- 0.1	+14.8	+ 0.17
914	666	+ 77	- 64	60	- 49	40	+ 1.6	+ 1.2	- 1.0	+12.2	- 0.52
915	666	+ 59	- 80	35	- 48	65	- 0.6	- 0.3	+ 0.5	+10.1	- 0.71
916	666	+100	+ 0	100	0	0	0.0	0.0	0.0	+14.2	+ 0.14
917	667	+ 99	+ 11	98	+ 11	1	- 2.2	- 2.2	- 0.2	+13.9	+ 0.22
918	667	+ 70	+ 71	49	+ 50	50	- 1.6	- 1.1	- 1.1	+ 6.5	+ 0.90
919	668	+ 93	- 35	87	- 33	12	- 2.9	- 2.7	+ 1.0	+14.9	- 0.03
920	668	+ 37	- 93	13	- 34	86	- 0.5	- 0.2	+ 0.5	+ 9.8	- 0.76
921	668	+ 50	- 86	25	- 44	75	+ 1.0	+ 0.5	- 0.9	+ 9.8	- 0.74

Sydney Observatory,
Sydney, N.S.W., 2000.

(Manuscript received 6.4.1977)

Journal and Proceedings, Royal Society of New South Wales, Vol. 110, pp. 87–92, 1977

Precise Observations of Minor Planets at Sydney Observatory During 1976

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ABSTRACT. Positions of 3 Juno, 6 Hebe, 7 Iris, 25 Phocaea, 39 Laetitia, 40 Harmonia and 148 Gallia obtained with the 23 cm camera are given.

The programme of precise observations of selected minor planets begun by W.H. Robertson in 1955 is being continued and the results for 1976 are given here. The method of observation are described in the first paper (Robertson 1958). All the plates were taken with the 23cm camera (scale 116" to the millimeter). Four exposures were taken on each plate, except those for 148 Gallia which had two exposures.

In Table 1 are given the means of the positions for all the exposures for each of two separate groups of reference stars at the mean of the exposure times. The differences in the results for two groups of reference stars average $0^{s}.030\ \sec\delta$ in right ascension and 0".40 in declination in the plates with four exposures. For those plates on which there were only two exposures the corresponding results were $0^{s}.026\ \sec\delta$ and 0".52. This leads to probable errors for the mean of the two results on the one plate of $0^{s}.013\ \sec\delta$ in right ascension and 0".17 for the plates with four exposures, and $0^{s}.011\ \sec\delta$ and 0".22 for the plates with two exposures.

The result for the first pair of images was compared with the result for the last pair by adding the motion computed from the ephemeris for the plates with four exposures. The means of the differences were $0^{s}.013\ \sec\delta$ in right ascension and 0".14 in declination. Comparison of the first and last exposures for the plates with two exposures gave mean differences of $0^{s}.057\ \sec\delta$ and 0".74. The images of the plates with only two exposures were, in general, of poorer quality than the other since they were of fainter objects. Along with the fact that there were fewer measurements to be meaned, this explains the larger differences. It is expected that the two results will be combined before they are used. However, they are published in the present form so that any correction to the positions of the reference stars may be conveniently applied by using the dependences from Table 2.

No correction has been applied for aberration, light time or parallax, but the factors give the parallax correction when divided by the distances. The column headed "O-C" gives the differences between the measured positions (corrected for parallax) and the position computed from the ephemeridies supplied by the Institute for Theoretical Astronomy in Leningrad.

In accordance with the recommendation of Commission 20 of the International Astronomical Union, Table 2 gives for each observation the positions of the reference stars and the dependences. The column headed "R.A." and "Dec." give the seconds of time and arc with the proper motion correction applied to bring the catalogue position to the epoch of the plate. The column headed "Stars" gives the Durchmusterung number taken from either the AGK3 or SAO catalogue. The first column gives a serial number which cross-references Table 1 and Table 2 and also the catalogue from which the reference stars were taken.

All plates were reduced by both the methods of dependences and by first order plate constants using the same six reference stars. The r.m.s. residuals of the reference stars was 0".2 for AGK3 stars and 0".6 for SAO stars.

The plates were measured by Mrs. A. Brown, Miss J. Fitt and Miss D. Teale who also assisted with the reductions. The observers at the telescope were D. S. King (K), T.L. Morgan (M), W.H. Robertson (R) and K.P. Sims (S).

References:

Robertson, W.H., 1958. Precise observations of minor planets at Sydney Observatory during 1955 and 1956. *J. Roy. Soc. N.S.W. 92, 18-23. Sydney Observatory Papers No. 33*

TABLE 1

TABLE 1

POSITIONS OF MINOR PLANETS

No.		R.A. (1950.0) h m s	Dec. (1950.0) o ' "	Parallax Factors s	"	O - C s	"	
	3 Juno							
	1976 U.T.							
1417	Mar. 09.57017	10 37 12.681	+05 45 40.45	+0.038	-5.56	-0.01	-0.2	M
1418	Mar. 09.57017	10 37 12.678	+05 45 40.38					
1419	Mar. 29.49720	10 25 04.260	+08 38 58.55	+0.005	-5.90	+0.03	+0.3	R
1420	Mar. 29.49720	10 25 04.251	+08 38 58.65					
1421	Apr. 06.47842	10 22 31.290	+09 30 34.60	+0.020	-6.00	-0.01	-0.1	R
1422	Apr. 06.47842	10 22 31.280	+09 30 34.46					
1423	Apr. 20.44093	10 21 42.695	+10 32 12.70	+0.024	-6.11	+0.01	-0.5	R
1424	Apr. 20.44093	10 21 42.687	+10 32 12.20					
1425	Apr. 28.44039	10 23 15.220	+10 51 38.06	+0.087	-6.09	-0.01	0.0	S
1426	Apr. 28.44039	10 23 15.206	+10 51 38.43					
1427	May. 04.40008	10 25 16.873	+10 59 05.86	+0.009	-6.16	0.00	-0.2	M
28	May. 04.40008	10 25 16.884	+10 59 05.56					
29	May. 18.37473	10 32 36.877	+10 55 37.96	+0.033	-6.15	-0.01	-0.2	R
1430	May. 18.37473	10 32 36.882	+10 55 37.38					
1431	May. 24.35881	10 36 42.505	+10 46 11.11	+0.025	-6.14	-0.04	+0.1	K
1432	May. 24.35881	10 36 42.553	+10 46 10.62					
1433	May. 31.33968	10 42 06.386	+10 29 49.15	+0.014	-6.11	0.00	-0.3	M
1434	May. 31.33968	10 42 06.386	+10 29 49.38					
	6 Hebe							
	1976 U.T.							
1435	July 08.77489	23 57 09.670	-04 35 31.27	-0.022	-4.29	-0.02	-0.5	K
1436	July 08.77489	23 57 09.645	-04 35 31.74					
1437	July 19.76125	00 08 45.320	-05 18 13.28	+0.003	-4.20	+0.03	-0.1	S
1438	July 19.76125	00 08 45.342	-05 18 12.80					
1439	July 29.73650	00 17 09.759	-06 26 01.77	-0.007	-4.04	+0.03	-0.8	K
1440	July 29.73650	00 17 09.805	-06 26 01.30					
1441	Aug. 03.72605	00 20 28.602	-07 11 03.24	-0.004	-3.90	+0.02	-0.7	M
1442	Aug. 03.72605	00 20 28.606	-07 11 03.16					
1443	Sep. 13.62625	00 21 01.078	-16 59 06.72	+0.034	-2.55	+0.04	+1.4	S
1444	Sep. 13.62625	00 21 01.072	-16 59 06.84					
1445	Sep. 20.58474	00 16 58.971	-18 44 18.08	-0.029	-2.29	-0.01	+0.7	R
1446	Sep. 20.58474	00 16 58.908	-18 44 18.07					
1447	Nov. 04.45911	23 59 57.763	-22 32 49.59	0.000	-1.72	+0.01	0.0	S
1448	Nov. 04.45911	23 59 57.773	-22 32 48.07					
	7 Iris							
	1976 U.T.							
1449	May. 24.76307	20 40 30.361	-14 52 17.28	-0.018	-2.85	-0.04	+0.3	M
1450	May. 24.76307	20 40 30.414	-14 52 18.00					
1451	May. 31.74917	20 42 25.916	-14 23 39.39	-0.006	-2.91	-0.03	+0.2	K
1452	May. 31.74917	20 42 25.877	-14 23 39.06					
1453	June 07.72320	20 43 05.340	-13 58 35.98	-0.029	-2.98	-0.03	-0.5	R
1454	June 07.72320	20 43 05.334	-13 58 34.98					
1455	June 08.72152	20 43 04.478	-13 55 19.20	-0.026	-2.99	-0.05	-0.1	R
1456	June 08.72152	20 43 04.555	-13 55 18.77					
1457	July 05.65402	20 32 09.334	-13 03 15.82	+0.018	-3.11	0.00	+0.1	K
1458	July 05.65402	20 32 09.356	-13 03 16.08					
1459	July 19.61076	20 19 31.420	-13 04 57.75	+0.029	-3.11	+0.04	-0.1	S
1460	July 19.61076	20 19 31.327	-13 04 56.64					
1461	July 27.57269	20 11 12.374	-13 13 11.43	-0.004	-3.08	-0.01	+0.2	K
1462	July 27.57269	20 11 12.400	-13 13 11.79					
1463	Aug. 03.54606	20 03 52.934	-13 23 27.98	-0.011	-3.06	-0.01	+0.4	M
1464	Aug. 03.54606	20 03 53.041	-13 23 27.16					
1465	Aug. 18.50215	19 50 11.908	-13 50 08.28	+0.009	-2.99	0.00	+0.5	S
1466	Aug. 18.50215	19 50 11.891	-13 50 08.47					

TABLE 1 (cont.)

POSITIONS OF MINOR PLANETS

No.		R.A. (1950.0) h m s	Dec. (1950.0) ° ' "	Parallax Factors s	"	O - C s	"	
	7 Iris (cont.)							
	1976 U.T.							
1467	Aug. 19.49930	19 49 27.152	-13 51 58.63	+0.010	-2.99	-0.03	+0.7	S
1468	Aug. 19.49930	19 49 27.087	-13 51 58.14					
1469	Sep. 14.41120	19 40 51.056	-14 30 41.28	-0.025	-2.89	+0.01	+0.1	R
1470	Sep. 14.41120	19 40 51.062	-14 30 41.85					
	25 Phocaea							
	1976 U.T.							
1471	May 03.76039	18 54 03.021	+00 30 06.87	+0.014	-4.94	-0.01	-1.3	R
1472	May 03.76039	18 54 03.035	+00 30 07.10					
1473	May 24.71360	19 03 38.674	+08 18 39.20	+0.037	-5.88	-0.02	-0.5	M
1474	May 24.71360	19 03 38.677	+08 18 38.96					
	39 Laetitia							
	1976 U.T.							
1475	Mar. 09.62833	12 20 30.435	+03 55 59.79	-0.005	-5.34	+0.01	-0.1	M
1476	Mar. 09.62833	12 20 30.462	+03 55 59.67					
1477	Mar. 29.56258	12 05 47.977	+06 29 00.59	-0.008	-5.65	-0.01	+0.2	R
1478	Mar. 29.56258	12 05 47.970	+06 29 01.11					
1479	Apr. 20.50121	11 51 52.716	+08 32 42.16	+0.017	-5.89	-0.01	-0.4	M
1480	Apr. 20.50121	11 51 52.708	+08 32 41.70					
1481	May 20.40632	11 46 25.490	+09 13 16.01	-0.011	-5.96	+0.01	-0.2	R
1482	May 20.40632	11 46 25.485	+09 13 15.66					
1483	May 31.38934	11 48 54.100	+08 53 17.51	+0.012	-5.93	0.00	-0.3	M
1484	May 31.38934	11 48 54.072	+08 53 17.51					
	40 Harmonia							
	1976 U.T.							
1485	May 05.71730	18 16 56.386	-21 14 17.00	-0.013	-1.90	-0.04	+0.1	R
1486	May 05.71730	18 16 56.400	-21 14 16.26					
1487	May 31.64588	18 04 58.818	-21 53 53.60	+0.012	-1.79	+0.01	0.0	K
1488	May 31.64588	18 04 58.914	-21 53 52.95					
1489	June 07.61087	17 58 30.131	-22 07 41.63	-0.025	-1.76	0.00	-0.2	R
1490	June 07.61087	17 58 30.204	-22 07 41.15					
1491	July 05.53388	17 29 06.748	-22 59 45.23	+0.040	-1.63	-0.01	+0.6	K
1492	July 05.53388	17 29 06.702	-22 59 44.76					
1493	July 16.48002	17 20 38.232	-23 17 12.56	-0.020	-1.59	-0.04	+1.1	K
1494	July 16.48002	17 20 38.134	-23 17 12.83					
1495	July 29.45001	17 15 24.744	-23 37 59.39	+0.011	-1.53	-0.06	+1.0	S
1496	July 29.45001	17 15 24.762	-23 38 00.13					
1497	Aug. 18.38939	17 18 38.559	-24 13 07.30	-0.017	-1.44	-0.01	+0.5	K
1498	Aug. 18.38939	17 18 38.496	-24 13 06.95					
	148 Gallia							
	1976 U.T.							
1499	June 02.68894	19 14 56.976	+04 25 42.44	+0.012	-5.43	-0.07	0.0	K
1500	June 02.68894	19 14 56.968	+04 25 42.98					
1501	July 19.53105	18 39 33.054	+01 25 51.26	-0.003	-5.07	-0.07	+1.2	S
1502	July 19.53105	18 39 33.030	+01 25 50.79					
1503	July 27.51487	18 33 31.892	+00 09 49.77	+0.025	-4.90	-0.03	-0.4	K
1504	July 27.51487	18 33 31.930	+00 09 49.12					
1505	Aug. 18.43779	18 23 07.730	-03 50 59.17	-0.003	-4.37	-0.08	+0.8	K
1506	Aug. 18.43779	18 23 07.696	-03 50 58.76					

TABLE 2

REFERENCE STAR POSITIONS AND DEPENDENCES

No.	Star	Depend.	R.A.	Dec.	No.	Star	Depend.	R.A.	Dec.
1417	+ 7 2339	0.314544	41.210	41.10	1418	+ 5 2359	0.361320	25.590	47.92
AGK3	+ 5 2374	0.309125	44.993	04.47	AGK3	+ 6 2329	0.265840	14.472	29.09
	+ 6 2335	0.376331	02.414	39.24		+ 6 2339	0.372840	36.400	37.09
1419	+ 9 2353	0.332811	15.494	40.38	1420	+ 8 2355	0.331546	43.360	27.11
AGK3	+ 9 2357	0.329844	24.353	35.10	AGK3	+ 9 2356	0.291070	22.328	54.80
	+ 8 2370	0.337346	30.311	13.86		+ 9 2364	0.377384	33.544	12.19
1421	+ 9 2343	0.335182	24.957	56.07	1422	+ 9 2341	0.321230	51.294	58.63
AGK3	+10 2147	0.317978	23.434	11.71	AGK3	+11 2223	0.351658	03.179	53.43
	+10 2154	0.346840	38.987	35.90		+ 9 2359	0.327112	32.760	01.25
1423	+10 2143	0.298504	18.868	43.38	1424	+11 2210	0.324855	50.035	49.20
AGK3	+11 2220	0.306297	19.344	28.79	AGK3	+10 2146	0.332872	41.863	29.69
	+11 2223	0.395200	03.179	53.43		+11 2228	0.342273	27.026	03.99
1425	+10 2145	0.363336	27.572	16.61	1426	+12 2203	0.284180	57.977	16.23
AGK3	+11 2220	0.302736	19.344	28.79	AGK3	+10 2147	0.355706	23.434	11.71
	+11 2236	0.333927	08.878	30.25		+11 2235	0.360114	41.574	57.77
1427	+11 2222	0.332077	47.311	39.07	1428	+12 2208	0.360256	04.254	35.90
AGK3	+10 2153	0.359047	04.078	02.47	AGK3	+11 2228	0.345598	27.026	03.99
	+11 2238	0.308876	12.676	52.81		+11 2243	0.294146	10.510	55.84
1429	+11 2243	0.322149	10.509	55.84	1430	+12 2224	0.353376	53.637	33.59
AGK3	+12 2235	0.352834	27.980	25.92	AGK3	+10 2170	0.325860	52.040	20.53
	+10 2174	0.325017	06.649	25.21		+11 2255	0.320763	16.021	30.80
1431	+12 2232	0.324764	19.681	16.94	1432	+10 2174	0.302644	06.649	25.21
AGK3	+10 2182	0.341428	43.106	34.76	AGK3	+12 2239	0.350267	59.875	17.87
	+11 2267	0.333807	57.226	58.14		+10 2190	0.347088	41.719	24.38
1433	+11 2266	0.363999	36.271	20.15	1434	+11 2267	0.262875	57.226	58.14
AGK3	+ 9 2399	0.317849	47.182	56.60	AGK3	+ 9 2400	0.360746	55.656	12.38
	+11 2282	0.318151	25.429	20.01		+11 2278	0.376380	28.987	25.37
1435	- 5 6088	0.290730	04.661	01.20	1436	- 5 6093	0.393154	17.894	00.32
SAO	- 4 5989	0.377952	35.418	27.64	SAO	- 6 6337	0.283916	26.204	21.69
	- 4 6013	0.331318	46.789	26.79		- 4 6003	0.322930	58.050	06.14
1437	- 5 6117	0.304232	13.227	40.64	1438	- 5 2	0.358632	02.202	30.71
SAO	- 6 14	0.328708	11.294	57.38	SAO	- 6 21	0.311564	46.344	14.42
	- 5 27	0.367060	01.509	02.21		- 5 23	0.329804	53.972	28.67
1439	- 7 32	0.304680	20.452	11.60	1440	- 8 29	0.346940	08.889	03.69
SAO	- 5 40	0.339425	39.546	36.18	SAO	- 6 46	0.326433	18.458	41.59
	- 7 44	0.355894	03.343	06.33		- 6 60	0.326626	16.216	51.27
1441	- 9 54	0.332106	40.360	31.80	1442	- 8 39	0.265855	09.689	19.74
SAO	- 7 44	0.404491	03.343	06.33	SAO	- 6 58	0.454990	28.736	00.43
	- 6 67	0.263402	23.174	40.10		- 8 65	0.279155	35.113	10.91
1443	-16 51	0.327876	12.531	37.78	1444	-16 52	0.402434	28.666	04.47
SAO	-17 43	0.362740	59.710	31.64	SAO	-17 55	0.208046	58.673	12.14
	-18 62	0.309384	13.304	27.42		-18 52	0.389520	08.762	38.83
1445	-18 34	0.331176	01.307	23.76	1446	-20 32	0.350682	49.990	35.32
SAO	-20 42	0.339772	14.549	48.47	SAO	-18 38	0.343082	20.153	38.96
	-18 44	0.329052	41.785	27.41		-19 54	0.306236	25.076	30.63
1447	-21 6513	0.326364	29.261	32.34	1448	-2318114	0.382938	28.205	18.46
SAO	-2318127	0.370832	56.615	46.01	SAO	-2216550	0.311524	40.000	56.41
	-2318132	0.302804	27.995	55.62		-2318135	0.305538	09.740	16.46
1449	-14 5821	0.338754	02.206	00.02	1450	-15 5750	0.344804	39.845	40.36
SAO	-15 5767	0.388916	46.385	04.77	SAO	-14 5829	0.310074	26.855	25.60
	-15 5775	0.272330	57.701	31.76		-15 5785	0.345123	23.532	44.42
1451	-14 5829	0.308325	26.855	25.60	1452	-14 5821	0.273922	02.206	00.02
SAO	-15 5767	0.343935	46.385	04.77	SAO	-15 5772	0.378355	36.925	36.94
	-14 5855	0.347740	49.039	40.21		-14 5856	0.347723	58.971	48.22
1453	-14 5829	0.315730	26.855	25.60	1454	-14 5826	0.359826	42.465	44.11
SAO	-13 5755	0.334980	44.640	12.04	SAO	-15 5790	0.299795	21.707	04.14
	-15 5793	0.349290	51.103	07.47		-13 5761	0.340380	32.324	19.79
1455	-14 5821	0.325998	02.206	00.02	1456	-13 5734	0.277973	09.493	59.77
SAO	-13 5755	0.342733	44.640	12.04	SAO	-15 5785	0.365208	23.532	44.42
	-15 5802	0.331269	21.711	38.57		-14 5855	0.356828	49.039	40.21
1457	-14 4780	0.344222	42.756	26.59	1458	-13 5695	0.370106	45.169	40.02
SAO	-13 5700	0.357970	03.213	23.01	SAO	-13 5702	0.307794	26.422	53.00
	-12 5790	0.297809	08.244	36.41		-13 5720	0.322100	35.903	21.38

TABLE 2 (cont.)

REFERENCE STAR POSITIONS AND DEPENDENCES

No.	Star	Depend.	R.A.	Dec.	No.	Star	Depend.	R.A.	Dec.
1459	-13 5636	0.356374	53.730	21.16	1460	-13 5639	0.266491	37.702	34.44
SAO	-14 5733	0.288982	48.077	55.18	SAO	-12 5704	0.367666	49.826	33.97
	-12 5712	0.354644	07.188	42.20		-13 5656	0.365842	35.381	47.13
1461	-14 5664	0.343942	42.151	47.53	1462	-12 5659	0.324108	43.003	01.60
SAO	-12 5674	0.331036	23.946	48.39	SAO	-14 5677	0.377146	21.849	42.64
	-13 5624	0.325022	39.124	19.83		-13 5630	0.298735	48.206	30.37
1463	-12 5635	0.339223	36.111	42.54	1464	-13 5565	0.373538	48.141	23.28
SAO	-14 5636	0.368442	07.981	25.20	SAO	-12 5644	0.329266	37.417	50.02
	-13 5598	0.292335	29.159	01.05		-14 5652	0.297196	48.157	00.54
1465	-14 5559	0.352513	10.975	44.68	1466	-14 5567	0.303872	44.199	16.91
SAO	-13 5506	0.335386	20.625	24.84	SAO	-12 5563	0.338038	20.231	23.25
	-14 5593	0.312101	29.378	17.46		-14 5590	0.358090	06.552	30.49
1467	-13 5481	0.344948	26.994	33.01	1468	-13 5492	0.344710	30.397	23.51
SAO	-13 5501	0.313188	53.195	35.32	SAO	-14 5571	0.313864	18.547	50.38
	-14 5590	0.341864	06.552	30.49		-14 5593	0.341426	29.378	17.46
1469	-14 5499	0.307483	21.862	39.96	1470	-15 5431	0.288972	09.629	17.45
SAO	-15 5448	0.342096	32.428	14.38	SAO	-13 5459	0.367210	43.610	14.42
	-14 5537	0.350420	13.989	46.14		-14 5531	0.343818	09.831	12.06
1471	+ 1 3816	0.369805	17.828	58.82	1472	- 0 3589	0.286526	57.277	08.26
AGK3	+ 0 4054	0.279632	13.254	44.92	AGK3	+ 1 3828	0.354045	47.155	30.81
	- 0 3617	0.350563	33.664	49.68		+ 0 4063	0.359428	59.846	03.71
1473	+ 8 3957	0.316932	19.395	17.41	1474	+ 7 3947	0.345446	33.781	44.95
AGK3	+ 7 3961	0.325425	57.686	09.92	AGK3	+ 8 3975P	0.328407	28.710	24.99
	+ 8 3981	0.357643	24.680	40.83		+ 7 3971	0.326146	00.662	13.82
1475	+ 5 2613	0.317862	25.931	04.79	1476	+ 4 2602P	0.392019	34.906	29.35
AGK3	+ 3 2638	0.387274	56.924	45.57	AGK3	+ 4 2608	0.323830	28.661	27.55
	+ 4 2613	0.294864	14.353	28.47		+ 4 2619	0.284150	43.156	24.90
1477	+ 6 2550	0.279700	20.991	54.51	1478	+ 7 2511	0.331416	49.089	34.71
AGK3	+ 6 2551	0.379351	22.549	59.87	AGK3	+ 7 2519	0.338956	35.434	04.87
	+ 7 2520	0.340949	34.619	24.36		+ 6 2560	0.329628	58.921	30.81
1479	+ 8 2547	0.315174	02.724	03.98	1480	+ 8 2549	0.359696	13.003	56.96
AGK3	+ 9 2554	0.340442	17.582	56.00	AGK3	+ 9 2558	0.312078	36.260	54.22
	+ 9 2567	0.344384	02.580	52.99		+ 9 2564	0.328226	57.820	53.39
1481	+ 8 2540	0.320757	23.352	37.68	1482	+ 9 2543	0.312660	29.579	45.68
AGK3	+10 2336	0.342701	54.178	04.06	AGK3	+ 9 2551	0.359496	04.531	52.25
	+10 2350	0.336542	52.715	50.11		+10 2345	0.327844	27.609	03.12
1483	+10 2339	0.307470	50.941	30.35	1484	+ 8 2541	0.343334	34.923	27.28
AGK3	+ 8 2547	0.365010	02.724	03.98	AGK3	+10 2350	0.383667	52.715	50.10
	+ 9 2558	0.327521	36.259	54.22		+ 9 2557	0.273000	34.025	23.88
1485	-20 5078	0.287048	54.667	25.31	1486	-2212794	0.343340	08.689	18.76
SAO	-21 4954	0.373013	16.538	51.48	SAO	-20 5097	0.278694	34.259	21.64
	-21 4961	0.339940	17.567	47.20		-21 4963	0.377965	59.560	29.85
1487	-2212509	0.335853	11.328	30.44	1488	-21 4842	0.309736	29.314	48.80
SAO	-2212617	0.302496	11.135	32.78	SAO	-21 4869	0.312524	55.732	40.87
	-20 5015	0.361651	27.525	40.54		-2212618	0.377741	15.612	54.66
1489	-2212373	0.254886	42.765	45.22	1490	-22 4470	0.268478	00.311	07.05
SAO	-21 4810	0.352526	07.718	52.50	SAO	-2212411	0.388230	22.000	47.79
	-2212530	0.392588	12.309	51.86		-21 4842	0.343292	29.314	48.79
1491	-2212058	0.355653	39.450	36.90	1492	-2212063	0.319204	04.771	46.88
SAO	-2313424	0.326986	25.591	13.82	SAO	-2313403	0.362462	06.820	56.35
	-2212094	0.317362	31.735	52.53		-21 4665	0.318335	22.498	52.52
1493	-2313331	0.287558	17.735	56.51	1494	-2313344	0.266304	24.128	25.97
SAO	-2212014	0.353110	03.711	54.42	SAO	-2212020	0.372058	14.741	16.13
	-2313379	0.359334	05.132	54.29		-2313373	0.361640	56.955	04.59
1495	-2211945	0.340830	58.988	51.35	1496	-2211935	0.306833	36.571	16.46
SAO	-2413250	0.322978	06.200	36.67	SAO	-2413262	0.328562	50.702	05.97
	-2313328	0.336192	07.482	02.24		-2313320	0.364605	23.793	02.07
1497	-2313313	0.336407	11.630	53.70	1498	-2413278	0.312855	51.173	19.58
SAO	-2413275	0.325618	35.147	19.00	SAO	-2313328	0.326252	07.482	02.24
	-2413327	0.337976	06.852	41.54		-2313353	0.360893	47.309	04.36
1499	+ 4 4031	0.318434	09.863	06.26	1500	+ 4 4039	0.354210	18.763	45.12
AGK3	+ 5 4101	0.336620	46.239	37.35	AGK3	+ 3 3964	0.275798	58.833	54.72
	+ 3 3978S	0.344946	41.663	13.20		+ 4 4065	0.369992	29.506	38.61

TABLE 2 (cont.)

REFERENCE STAR POSITIONS AND DEPENDENCES

No.	Star	Depend.	R.A.	Dec.	No.	Star	Depend.	R.A.	Dec.
1501	+ 1 3738	0.322614	39.785	30.80	1502	+ 1 3735	0.352116	18.202	08.28
AGK3	+ 2 3661	0.359196	09.193	59.59	AGK3	+ 1 3755	0.335816	42.424	23.38
	+ 0 2244*	0.318191	47.904	07.89		+ 1 3770	0.312068	02.763	47.78
1503	+ 0 3966	0.352847	33.204	10.56	1504	+ 0 3965	0.334754	30.354	32.10
AGK3	- 0 3510	0.308776	13.602	09.11	AGK3	+ 0 3971	0.351710	28.293	08.05
	+ 0 3985	0.338376	47.093	32.06		- 0 3528	0.313537	53.104	38.39
1505	- 4 4452	0.292943	58.513	39.19	1506	- 4 4451	0.416906	54.408	49.87
SAO	- 3 4282	0.314580	45.382	44.67	SAO	- 3 4283	0.282688	55.322	50.00
	- 3 4288	0.392477	46.842	25.78		- 2 4643	0.300406	46.894	54.16

* AGK3 No.

Sydney Observatory,
Sydney, N.S.W., 2000.

(Manuscript received 6.4.1977)

Journal and Proceedings, Royal Society of New South Wales, Vol. 110, pp. 93–94, 1977

The Essential Oil of the Fly-Repellent Shrub, *Pterigeron bubakii*

I. A. Southwell and J. R. Maconochie

ABSTRACT. Steam distillation of *Pterigeron bubakii*, a shrub used by the Barkly Tableland aborigines as a fly repellent, yielded an essential oil containing β-caryophyllene and p-cymene as major components. Activity tests on the housefly showed no significant repellency.

INTRODUCTION

The genus *Pterigeron* (Compositae) comprises a number of aromatic species endemic to Australia currently undergoing taxonomic revision (C.R. Dunlop, pers. comm.).

Pterigeron bubakii Comin is a small subshrub which is locally common throughout the black soil plains of the Barkly Tablelands in the Northern Territory and extending into both Queensland and Western Australia in similar habitats. The plant is unpalatable to stock and can form relatively thick communities in overgrazed areas. On Muckaty Station, N.T., the aboriginal people used this species as a fly repellent. The women would place a coolamon containing a baby amongst the bushes to keep the bushflies away (L. Ulyatt, pers. comm.). Local inhabitants also placed a sprig in their hats as a repellent.

ESSENTIAL OIL COMPOSITION

Dried plant material (274g) was steam-distilled with cohobation in an all-glass apparatus (Hughes 1970) to yield 0.2% of volatile oil. Gas liquid chromatography on a Perkin-Elmer 900 gas chromatograph with a flame ionisation detector indicated two main constituents and several minor components. These were eluted with helium from an FFAP 15m x 0.5mm i.d. support coated open tubular column maintained at 60° for 3 minutes and then programmed at 6° per minute to 170°. The following components were identified by their mass spectra determined on an AEI MS 30 spectrometer and confirmed by co-chromatography with authentic samples: α-pinene (2%, relative retention time with respect to α-pinene (RR_t) 1.00), β-pinene (3%, RR_t 1.51), α-phellandrene (6%, RR_t 2.10), limonene (7%, RR_t 2.38), p-cymene (43%, RR_t 2.86), and β-caryophyllene (18%, RR_t, 5.37). The identity of the major components p-cymene and caryophyllene was further confirmed by infra-red spectroscopy. Percentages were determined with a Hewlett-Packard 3370 A electronic integrator.

REPELLENCY

Both the steam volatile oil and the component considered most likely to be active (Waterhouse 1947; McCulloch and Waterhouse 1947; Kerr, 1951) were tested as fly-repellents. Concentrations of 0.031-2.000 µg per µl of (i) β-caryophyllene and (ii) the whole oil were shown to have no significant repellency against the housefly for periods of up to 30 minutes duration.

CONCLUSION

The components identified in the essential oil of *Pterigeron bubakii* are odiferous and have been used for the scenting of soaps and cosmetics (Guenther 1949). As repellency tests showed no significant activity in the essential oil or its major sesquiterpene component β-caryophyllene, deactivation during distillation may have occurred.

ACKNOWLEDGEMENTS

The authors would like to thank the Mass Spectometry Unit, School of Chemistry, University of Sydney, for the g.l.c.-m.s. analysis, Mrs. B. Toyer, Museum of Applied Arts and Sciences, Sydney, for the g.l.c. and co-g.l.c. analysis and Dr. G. Holan, Division of Applied Organic Chemistry, C.S.I.R.O., Melbourne, for biological testing.

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(Manuscript received 18.11.76)
(Manuscript received in final form 24.5.77)

Journal and Proceedings, Royal Society of New South Wales, Vol. 110, pp. 95–98, 1977

A Bottom Profile Across Lake Eyre North, South Australia

J. A. DULHUNTY

ABSTRACT. A bottom profile constructed from soundings obtained across the northern half of Lake Eyre North, shows cross-sectional features of the Warburton and Kalaweerina Grooves of tectonic origin, and areas termed the Cooper and Neales Depressions believed to have been formed by outwash of estuarine sediments and inshore scouring. Very recent or contemporary tectonic development of the grooves, supports previously recorded evidence of contemporary tectonism.

INTRODUCTION

Two long narrow parallel sided grooves extend from north to south across the northern half of the bed of Lake Eyre North, which slopes gently to the south at an average gradient of 3 cm per km (Fig. 1A). They are almost linnear, with very slight uniform curvature, and are approximately parallel to each other and to the general alignment of the eastern and western shores of the lake. The Warburton Groove is the wider and longer, extending some 85 km from near the northern shore towards Belt Bay. The Kalaweerina Groove is narrower and shorter extending about 40 km towards Madigan Gulf.

Floodwaters entering through the estuaries of the Warburton River and its distributary Kalaweerina Creek, flow south along the Warburton and Kalaweerina Grooves towards Belt Bay and Madigan Gulf respectively. Water from minor floodings, and the first water to arrive before major floodings, flows along the grooves as channels. When the whole lake bed is covered during major flooding, the grooves are completely submerged. As they frequently carry flowing water, the grooves could normally be expected to become meandering water courses owing to the extremely low gradient of the surface over which they pass, and the unconsolidated nature of the lake bed silt in which they have developed. However, absence of meandering and their near linnear nature, strongly suggest tectonic origin and control rather than development from normal processes of flowing water.

Whilst the presence of the grooves was evident from aerial observation and photography, nothing was previously known about their depths or cross-sectional profiles. In 1974, while the lake bed was completely submerged by major flooding, the author obtained a number of soundings in the vicinity of the Cooper Estuary and south along the eastern shore. Also, in 1975 an east-west line of soundings was obtained across the lake from the Cooper Estuary, by R. Clark and A. and M. Atkinson in their boat Ibis, working in conjunction with an investigation by the author. These soundings gave a precise bottom profile across the lake and the two grooves, and also two depressed areas close to the eastern and western shores. Numerous additional soundings obtained during 1974-75 by J. A. T. Bye of Flinders University, and P. J. Dillon, J. C. Vandenberg, G. D. Will and J. Clark of the South Australian Department of Engineering and Water Supply (Pers. Com. 1974-76) confirmed the occurrence of the depression near the eastern shore extending south from the Cooper Estuary, for which the name "Cooper Groove" was proposed. However, the name "Cooper Depression" is preferred by the present author and used in this paper, as discussed later.

The purpose of the present paper is to record the data obtained by R. Clark and A. and M. Atkinson in conjunction with the author and the profile constructed across the lake, and to consider results, together with other observations, in relation to the significance and development of the geomorphological features concerned.

ORIGINAL OBSERVATIONS

The first recorded sighting of any part of the Warburton Groove was by J. Ross who in 1869 described water flowing from the northern shore across the bed of Lake Eyre towards a "deep channel of water" which was undoubtedly the Warburton Groove (Mason 1955). Fifty years later, G. H. Halligan (1923) made the first aerial examination of the lake and described and figured two tongues of water extending to the north, which were the two grooves, but he did not recognise them as linnear depressions. In 1929, Madigan (1930) described, as seen from the air, a dark area running north, in Lake Eyre North, which "appeared to be a depression in the lake bed". It was the Warburton Groove, and he was the first to see it as a groove-like feature. During the 1949-50 major flooding of the lake, the role of the Warburton Groove as a water channel was appreciated from aerial reconnaissance, and named the Warburton Groove by Bonython (1955, 1960), who also described water flowing along the Kalaweerina Groove but the name Kalaweerina was not used.

When regional vertical aerial photography became available in about 1960, the true form and full extent of the two grooves commenced to emerge, and was confirmed by a Skylark Rocket photograph taken from an altitude of 240 km in 1972 (Dulhunty 1975). The tectonic significance of the Warburton and Kalaweerina Grooves in association with the geological development of Lake Eyre, has been discussed by Wopfner and Twidale (1967) and Williams (1973). The first precise mapping of the two grooves by photointerpretations, and use of the

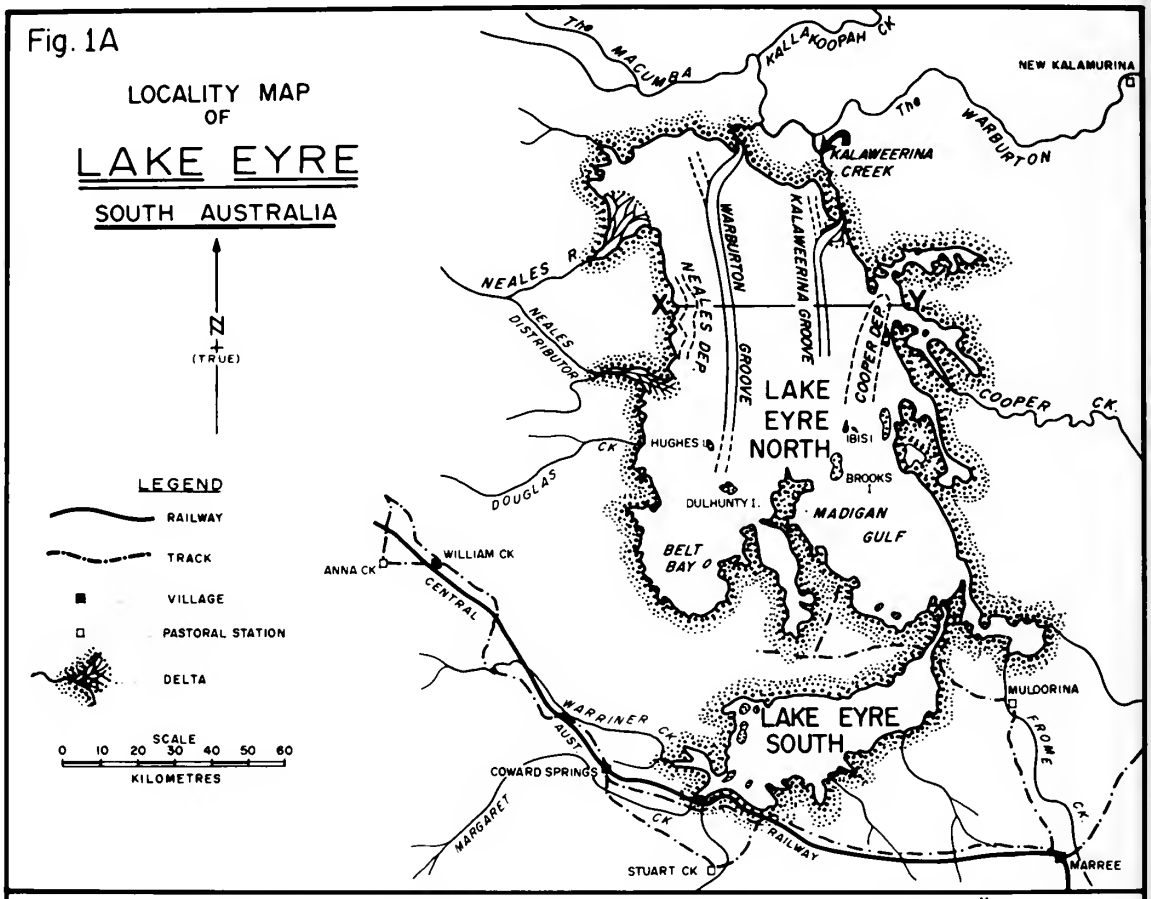
Fig. 1A
LOCALITY MAP OF
LAKE EYRE
SOUTH AUSTRALIA
N (TRUE)
LEGEND
RAILWAY
TRACK
VILLAGE
PASTORAL STATION
DELTA
SCALE
0 10 20 30 40 50 60
KILOMETRES
The MACUMBA
KALLAKOOPAH CK
NEW KALAMURINA
The WARBURTON
KALAWEERINA CREEK
WARBURTON GROOVE
KALAWEERINA GROOVE
NEALES R.
NEALES DISTRIBUTORY
NEALES DEP.
COOPER DEP.
COOPER CK.
LAKE EYRE NORTH
HUGHES I.
IBIS I.
BROOKS I.
DULHUNTY I.
MADIGAN GULF
DOUGLAS CK
BELT BAY
ANNA CK
WILLIAM CK
CENTRAL
WARRINER CK
AUST
COWARD SPRINGS
MARGARET CK
LAKE EYRE SOUTH
MULDORINA
FROME CK
RAILWAY
STUART CK
MARREE

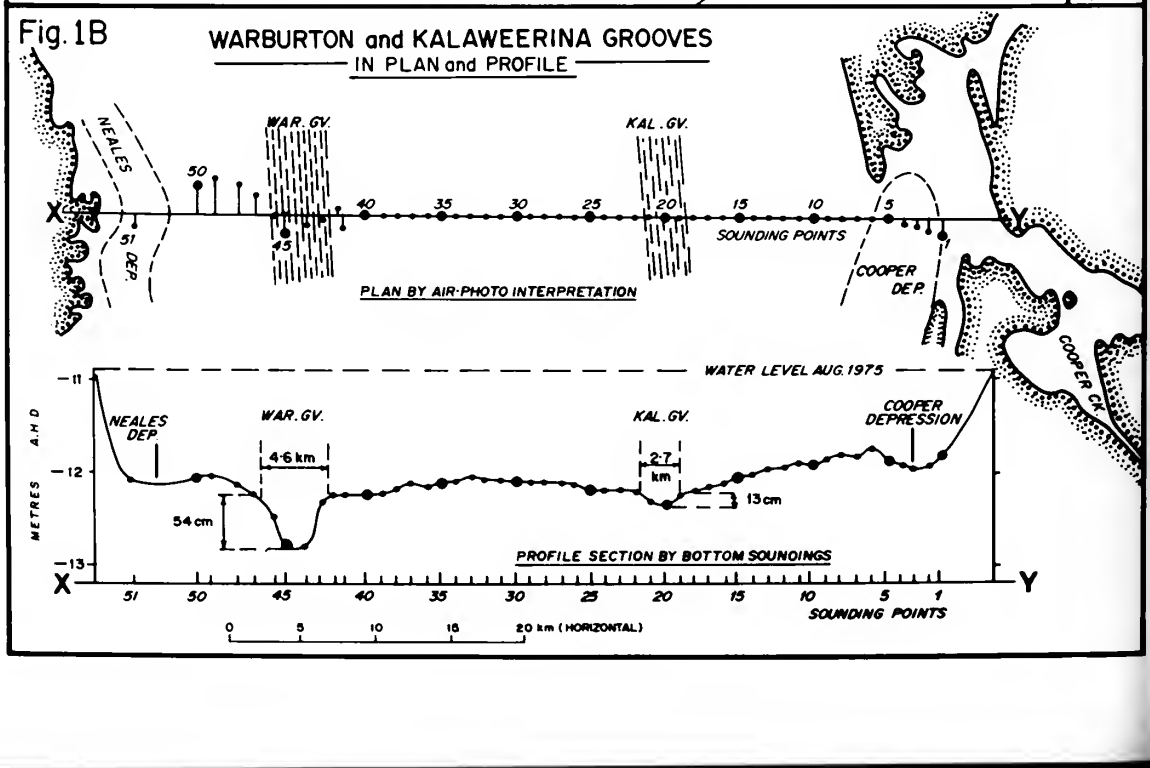
Fig. 1B
WARBURTON and KALAWEERINA GROOVES
IN PLAN and PROFILE
NEALES
WAR. GV.
KAL. GV.
SOUNDING POINTS
PLAN BY AIR-PHOTO INTERPRETATION
COOPER DEP.
COOPER CK.
WATER LEVEL AUG. 1975
NEALES DEP.
WAR. GV.
KAL. GV.
COOPER DEPRESSION
4·6 km
2·7 km
54 cm
13 cm
METRES A.H.D.
PROFILE SECTION BY BOTTOM SOUNDINGS
SOUNDING POINTS
0 5 10 15 20 km (HORIZONTAL)

name "Kalaweerina Groove" was by Williams (1973, 1975).

THE BOTTOM PROFILE

The positions of the Warburton and Kalaweerina Grooves, and the Neales and Cooper Depressions are illustrated in the locality map, Fig. 1A, together with the profile section line X-Y and river systems entering Lake Eyre.

Soundings were made from the sailing craft Ibis, with a graduated pole at points fixed by log line and compass course along the true west bearing of the section line X-Y. Where it was necessary to deviate from the true west bearing, sounding values were transferred from actual sounding points to the line X-Y, along north-south perpendiculars as illustrated in Fig. 1B. This was acceptable as deviation distances were relatively very small, and the significant depth changes under investigation were those in an east-west direction.

The detail plan of sounding points along the profile section X-Y is shown in Fig. 1B, together with the exact positions and widths of the Warburton and Kalaweerina Grooves, and the general areas of the Neales and Cooper Depressions, as determined by aerial photointerpretation. Immediately beneath this plan in Fig. 1B, is the profile section placed with shoreline points and sounding points directly beneath corresponding points in the plan. The profile was constructed by plotting measured depths, at sounding points, in relation to mean lake level of -11.1 m A.H.D.in August 1975. Extrapolation of the profile to the shorelines beyond closely spaced soundings, is indicated by broken lines.

RESULTS AND CONCLUSIONS

The profile constructed from soundings shows definite groove-like features corresponding closely in position and width with the Warburton and Kalaweerina Grooves plotted in plan from aerial photography. The Warburton Groove is the deeper and wider of the two. They stand out very clearly in profile, but their actual depths of 54 and 13 cm in relation to widths of 4.6 and 2.7 km respectively, indicate the extremely shallow nature of the grooves, and the "flatness" or remarkably low relief across the lake bed. There is a slope of 4 cm per km to the west, between the Cooper Depression and the Kalaweerina Groove, then a slight rise to a low ridge between the two grooves. Overall, the bed of the lake exhibits a slight average fall of about 8 mm per km from east to west, in the vicinity of the profile section.

The general areas of the Neales and Cooper Depressions, near the western and eastern shores are shown in plan by broken lines in Figs. 1A and 1B and appear in the profile section in Fig. 1B. They are visible in aerial photography of the dry lake bed, but differ considerably in appearance from the two grooves. They have ill-defined sides, are vague in shape and form, and lack definite orientation. From low altitude aerial observation of both areas in 1974-75, and examination of the Cooper Depression by boat in 1974, there appeared to be offshore silt or sand banks and inshore channels in the areas of the depressions. As they may be due to outwash sand and silt from the Cooper and Neales Estuaries, and inshore scouring by water flowing south along the shores, the term "depression" is used in this paper so as not to infer tectonic significance as in the case of the "grooves" in the profile.

The profile shows the eastern sides of the Warburton and Kalaweerina Grooves steeper than their western wides. When considered in relation to their widths of 4.6 and 2.7 km, this feature would seem to be of some significance, although uncertain in meaning. If the grooves are related to faulting it may mean similar elements of movement beneath each of the grooves. The long narrow nature of the grooves, and their well-defined sides, would seem to indicate sharp fault displacement rather than warping or flexing.

Floodwaters from the Warburton River and Kalaweerina Creek, flow south west across the lake bed, then into and south along their respective grooves (Fig. 1A). Aerial photography (South Australian Department of Lands 1961-64 photography) indicates continuation of the grooves to the north from the places where the floodwaters flow into them, as illustrated by broken lines in Fig. 1A. This strongly supports previous opinions that they originated as tectonic features. It also indicates that floodwaters flow along the grooves as pre-determined channels, and have not been able to develop meanders owing to continued or contemporary tectonic influences or controls. There is no evidence of antiquity of the grooves, and absence of any significant modification by flowing water may mean that they have developed very recently, or are at present developing as a result of contemporary tectonism evidence of which, at Lake Eyre, has been previously recorded by Wopfner and Twidale (1967), and Williams (1973, 1975).

ACKNOWLEDGEMENTS

It is wished to acknowledge (i) the co-operation of Messrs. R. Clark and M. and A. Atkinson, and use of their boat Ibis, in obtaining soundings across Lake Eyre North as described in the text, (ii) assistance of Muloorina Station in field investigations, (iii) funds provided by the Australian Research Grants Committee, and (iv) research facilities of the Department of Geology and Geophysics, University of Sydney.

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(Manuscript received 13.7.1977)

Journal and Proceedings, Royal Society of New South Wales, Vol. 110, pp. 99-110, 1977

Influence of Hydrothermal Treatment on Physical and Chemical Properties of Chrysotile Asbestos*

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ABSTRACT. Aqueous suspensions of natural chrysotile fibres of equivalent specific surface area, originating from Advocate, Balangero and Zidani, and synthetic chrysotile were treated hydrothermally at pressures ranging from 1 to 300 kp cm^{-2} and temperatures from 20 to 250°C for 2 hours to 120 days. The resulting solid and liquid phases were investigated by physical and chemical methods.

The influence of a second mechanical cleaning process and of hydrothermal treatment on structural, chemical and technical properties of the fibres and on the dissolved phase of chrysotile in water are presented. It can be demonstrated that the mechnical qualities of the fibres depend mainly on the constitution of the fibre surface, and to a lesser degree on the amounts of accessory minerals.

Thermodynamic data, as activation energies, activity product constants and Gibbs free energies are calculated and compared with those reported in literature.

INTRODUCTION

Of all asbestos minerals, chrysotile is the fibre most used in industry and accounts for more than 90% of the demand for asbestos fibres. The production of fibre has increased from the fifty tons at Thetford, Canada in 1877 to the world annual output of 4.3 million tons in 1975, an indication of the still growing economic significance of chrysotile (Lincoln, 1975). Compared with the quality of man-made fibres (glass filament, steel, carbon etc.) chrysotile has an important advantage in terms of basic material properties per unit cost. Chrysotile plays an essential role in the asbestos cement industry, and is used in a wide range of friction materials for transmitting power or converting kinetic energy into heat energy. All known substitutes fail on the grounds of efficiency, consistency, or cost effectiveness. Unfortunately the average extrapolated life for economical exploitation of chrysotile does not exceed forty years.

This study on chrysotile was stimulated by industry, on the one hand, and by unsolved problems in fundamental research, on the other. It differs from synthetic experiments (Bowen and Tuttle 1949, Yang 1960, 1961, and Kurczyk et al 1975) in that aqueous suspensions of fibrous chrysotile were used, instead of highly concentrated gels, with the aim to improve or modify the qualities of the fibres.

We exposed chrysotile fibres of equivalent specific surface areas to various hydrothermal conditions, and investigated the physical and chemical properties of the treated fibres. As the quantities of treated fibres were in the range of a few grams up to 50 g per run we were able to perform all analytical work on the same material.

Investigations on the properties of *ground* chrysotile in water are described by Holt and Clark (1960), Hostetler and Christ (1968), and Choi and Smith (1972). Ball and Taylor (1963) carried out similar experiments, but on a more applied basis by adding several oxides and hydroxides to the aqueous suspensions of chrysotile. In our study, however, the hydrothermal treatment was performed with *unground* chrysotile fibres under such conditions that, in most instances, the conversion of chrysotile into forsterite, talc, enstatite and antigorite did not take place. Our results are in agreement with recently developed model of Evans et al (1976) which was derived from field observation.

MATERIALS AND METHODS

The starting materials for the experiments consisted of chrysotile fibres of grade 4D from three different localities, Newfoundland, Italy and Greece.

Advocate asbestos (AM) originates from the Advocate deposit situated in the Burlington Peninsula, 5 km north of the small town of Baie Verte. The main body is a harzburgite with dunitic enclaves; it covers an area 3 to 5 km wide and 75 km long. The ultrabasics are mainly near the western contact, where the eruptives of Baie Verte are exposed. The fibre bearing rock (exploited area 1200m x 500m) is wrapped in dark chloritized schists of volcanic origin. The cross fibre is mined by open pit operation. Geological studies were published by Church (1969). The *Balangero* (BM) open pit mine is located in northern Italy, 30 km northwest of Turin in the hills of San Vittore. This slip fibre deposit occurs in northeastern digitation of the large pre-Triassic peridotitic massif of Lanzo. Although the Lanzo massif and the associated

* An extract from this publication was presented at the 25th International Geological Congress 1976 in Sydney entitled "Investigation of the Behaviour of Chrysotile under Hydrothermal Conditions".

sequence of green rocks have been studied for more than a century, there exists only one geological study of the Balangero deposit (Riccio, 1969). Riccio concludes that an original lherzolite has been serpentinised as well as antigorised. These phenomena as well as the fibre formation are attributed to alpine tectonics. The chrysotile asbestos from *Zidani* (ZM) belongs to the slip fibre type. The deposit is located in Thessalia, northern Greece and is mined by extensive underground operations. The ultrabasic body is an outlier of the large ophiolitic sequence of rocks forming Vourinos mountain. Macroscopic examination of the fibre bearing rocks shows consideration shearing. The country rocks are considered to be Jurassic. No geological study of Zidani is known.

The fibre containing rocks were processed in the mining companys' mills as follows: Separation of the fibres by crushing in mills; successive milling for opening and classification of the fibres according to their length and quality. Fibres with a specific surface area of about 20,500 cm^2g^{-1} (determined by N_2 -absorption) which did not differ more than 7% from each other, were used. In a wet cleaning process in the Company's labs particles smaller than 100 µm, i.e. the dust-fraction were removed. The remaining cleaned fibres were opened again to the above mentioned specific surface area and named AMC, BMC, ZMC.

Synthetic material, which we obtained through the kindness of Prof. de Vynck/Gent, was synthesised from gels in 15 days according to a method similar to that of Bowen and Tuttle (1949). The synthesised material showed DTA and X-ray diffraction peaks characteristic of chrysotile, but no fibrous texture could be observed under the microscope. Electron microscopic examination, however, showed fibrils of 700 to 12,000 Å in length with 40 to 70 Å inner and 140 to 240 Å outer diameters, together with relics of starting gels.

A hundred runs of aqueous suspensions of unground cleaned and uncleaned chrysotile fibres from Advocate, Balangero and Zidani were carried out in an oilbath and in 2 litre and 10 litre autoclaves. Pressures were varied from 1 to 300 atms. and temperatures from 2° to 250°C, and the length of runs from 2 hours to 120 days. Pressures

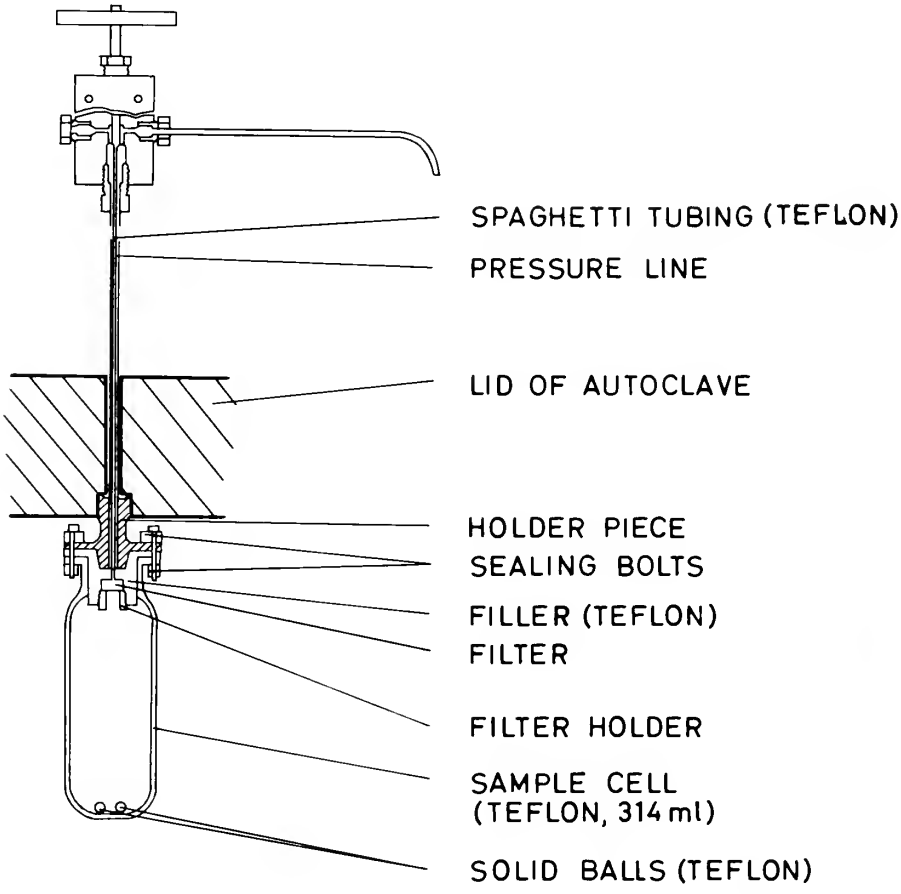

Figure 1. Bleeding Device in 2L-Autoclave after Dickson et al. (1963)

pressure P(kp cm^{-2})		1	1	50	1	50	100	200	100	200	300
temperature T(°C)		20	80	80	100	100	100	100	200	200	200
fibres	AM	X	X			X	X		X		
	ZM	X	X			X	X		X		
cleaned fibres	AMC	X	X	X	X			X			X
	BMC	X	X	X	X			X			X
	ZMC	X	X	X	X		X		X		X
dust-fraction	AM	X								X	
	BM	X								X	
synthetic chrysotile		X								X	

TABLE 1

CONDITIONS OF HYDROTHERMAL EXPERIMENTS IN OILBATH AND 2 LITRE AUTOCLAVE

fibre	P(kp cm^{-2})/ /T(°C)	conc. of chrysotile (%)	duration	additives +) (conc. 1%)
AM	50/150	2.9	80 hrs	B,S,A
	100/150	2.9	80 hrs	B,S,A
	200/150	2.9	80 hrs	B,S,A
	100/100	9	50 hrs	B,S
BM	100/100	9	100 hrs	B,S
	200/100	9	100 hrs	B,S
	100/200	9	100 hrs	B,S
	200/200	9	100 hrs	B,S
ZM	100/100	9	50 hrs	B,S
AMC	50/150	2.9	80 hrs	SZ
	100/150	2.9	80 hrs	SZ
	200/150	2.9	80 hrs	SZ
	100/200	9	100 hrs	B,S
	200/200	9	120 d	
BMC	100/200	9	100 hrs	B,S
	200/200	9	120 d	S
ZMC	100/200	9	100 hrs	B,S
	200/200	9	120 d	B

+) weight % of fibre

B = brucite

S = SiO_2

A = Al_2O_3

SZ = SiO_2 (liquid and solid, resp.) + 20% and 40% ZMC, resp.

TABLE 2

HYDROTHERMAL EXPERIMENTS IN 10 LITRE AUTOCLAVE

Figure 2. Aggregated chrysotile fibres from Balangero (mode: SEM).

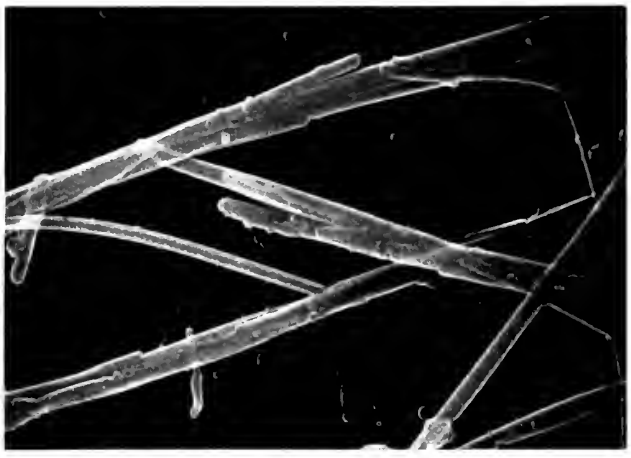

Figure 3. Chrysotile fibres from Zidani (mode: SEM).

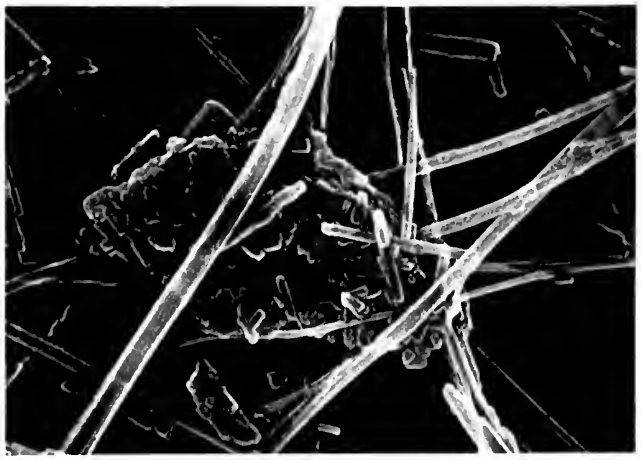

Figure 4. Aggregated particles in chrysotile (mode: SEM).

and temperatures were monitored and recorded by a ten-channel printer during the runs. The precision of the pressure and temperature regulation devices was 1% and 0.3%, respectively. Immediately after the termination of the runs the suspensions were filtered through 0.45 µm pore size filters, and the solid and liquid phases were analysed separately.

The reaction vessel and the 2 litre autoclaves were constructed in such a manner that enabled samples to be bled off during the runs (Fig. 1). The various hydrothermal conditions of the runs in the oilbath and the 2 litre autoclaves are compiled in Table 1. These experiments may be regarded as fundamental research, whereas those in closed 500 ml teflon vessels in the 10 litre autoclave are of a more applied character. The conditions of these experiments are listed in Table 2. In addition, analogous runs were tried in 0.01 normal ammonia. Of course, blanks were carried out for each run.

The solid phase was analysed by physical and chemical methods: the transition from single fibrils to aggregated bundles of fibres could be observed by electron microscopy and single fibres were identified by electron diffraction; X-ray diffraction revealed structural differences between serpentine minerals and made possible the determination of the contents of contaminating minerals. Chemical compositions of the solid state were determined by wet-chemical methods, X-ray fluorescence spectroscopy, instrumental neutron activation analysis and electronprobe microanalysis. The surface properties of the different kinds of fibres were investigated by zetapotential measurements. The mechanical properties of chrysotile asbestos in cement products were tested with respect to filtrability and strength (Hirner, 1976). The concentrations of hydrated magnesium and silicon in the liquid phase were analysed by atomic absorption and spectrophotometry, respectively.

For the various physical and chemical analyses the fibres were prepared in non destructive manner by suspension methods; for X-ray fluorescence analysis, the calcined samples were fused with lithium metaborate.

RESULTS

Characterisation of Starting Material

The inner and outer diameters of the three types of natural fibres range from 50 to 90 Å and from 200 to 500 Å, respectively, which is in general agreement with diameters observed by Yada (1971). Uncleaned Advocate fibres are well shaped and soft; those from Balangero are straight and not very flexible, and show geometric shapes in aggregates (Fig. 2). Uncleaned fibres from Zidani are not well shaped, scaly, with adhering particles (Fig. 3). Fig. 4 shows mineral particles which were identified as platy aggregates of lizardite and antigorite. These minerals were found in all kinds of fibres on a microscopic scale. Diffraction patterns proved our fibres to be mainly clinochrysotile; in addition antigorite was identified in BM, and orthocrysotile was found in ZM and the synthetic material. The contents of accessory minerals are presented in Table 3. The highest amounts of dolomite and magnetite were found in Zidani and Balangero fibres, respectively. The chemical compositions of the untreated fibres are illustrated on Figure 5. The groups of major, minor and trace elements including extreme traces are clearly separated. In spite of the small variations in the major elements a relatively high amount of magnesium is characteristic of the Advocate fibre and a relatively high amount of silica of the Zidani fibre. The surface charge differs between the three fibres; the following zetapotentials were determined: +54 mV for Advocate, +24 mV for Balangero and +18 mV for Zidani. The different surface potentials affect the different mechanical properties. Asbestos cement cakes with fibres from Advocate have a lower density, but higher strength (340 kp cm^{-2}) than those from Zidani (245 kp cm^{-2}).

TABLE 3

ACCESSORY MINERALS ASSOCIATED WITH CHRYSOTILE FIBRES (%) DETERMINED BY X-RAY DIFFRACTION ANALYSIS

Origin	Brucite	Dolomite	Calcite	Magnetite
Advocate	0.2	<0.1	0.4	2.5
Balangero	0.2	0.4	0.6	6.3
Zidani	<0.1	1.9	0.3	3.1

Influence of Mechanical Cleaning

Residual amounts of orthochrysotile in AM and antigorite in BM were almost quantitatively removed; in the Zidani fibre, however, orthochrysotile could not be removed, a fact which indicated that orthochrysotile is present as intergrown fibres. As the amounts of accessory minerals are reduced the integral intensities of the principal reflections (002) and (004) are increased by 25% in the Advocate fibre, by 17% in Balangero fibre, and by 9% in the Zidani fibre.

In the Balangero fibre the appreciable amounts of contaminating minerals could be removed down to the limits of detection, i.e. 0.1% for brucite, 0.1% for dolomite, 0.2% for calcite and 0.2% for magnetite. This holds true for magnetite in the Advocate fibre. Brucite in this fibre and dolomite and magnetite in the Zidani fibre, however, are so intimately intergrown that they still remained after mechanical processing. This procedure proved to be efficient in reducing the chromium content in the Advocate and Zidani fibres by a factor of 2.5 to 3.5. In the Balangero fibre the nickel, manganese and titanium contents were lowered by a factor of about 2. Because of the removal of interfering and specifically heavier contaminants the density of asbestos cement decreased, as if the fibre material had passed a cleaning process. Filtrability and strength of the Balangero and Zidani fibres increased simultaneously which clearly indicates that the fibres are the only

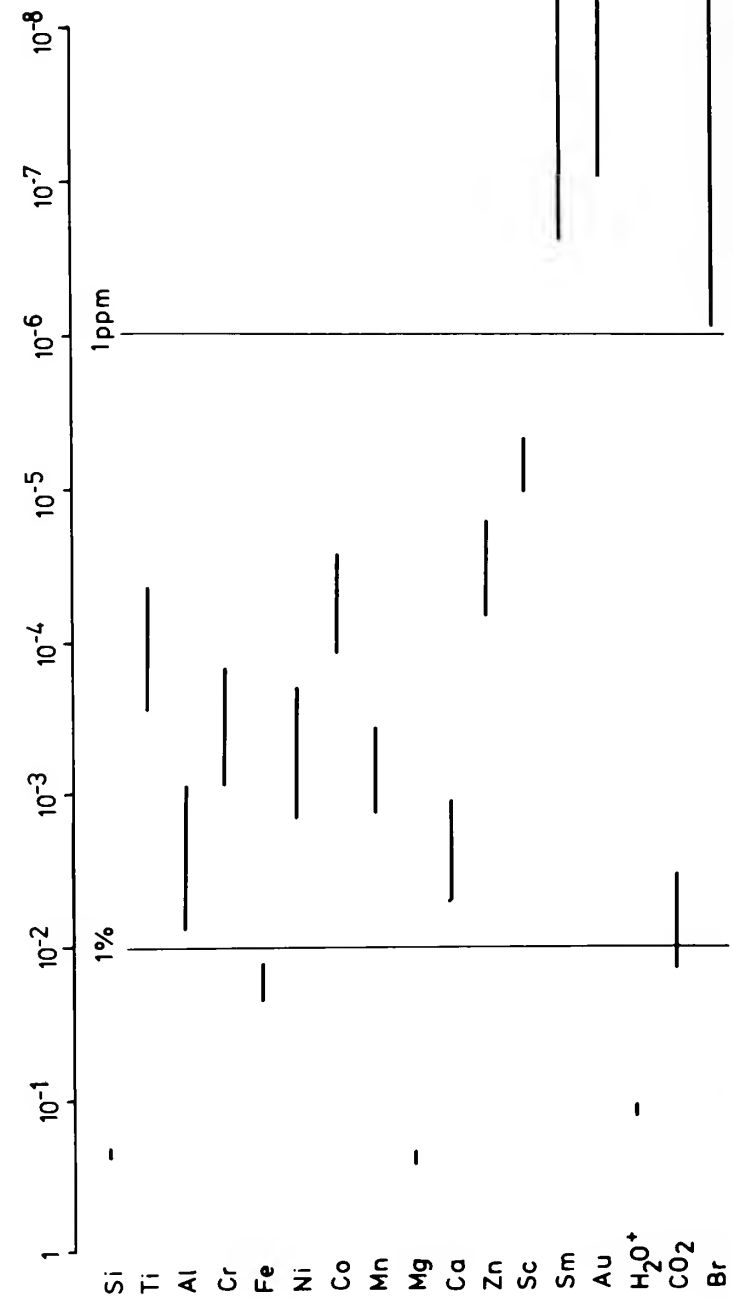

Figure 5. Chemical Compositions of Fibres originating from Advocate, Balangero and Zidani.

reinforcing material in asbestos cement products. The soft cleaned fibres from Advocate have a lower filtrability and a slightly better strength than the uncleaned material, because the platy lumps of lizardite were removed.

Influence of Hydrothermal Treatment

Solid Phase

In principle, the mineralogy was not influenced except for a small portion of Zidani chrysotile - perhaps the orthotype - which was converted into antigorite. This conversion was prevented by the addition of 1% brucite.

The integral intensities of the main reflections and therefore the concentrations of natural and synthetic chrysotile were not increased by hydrothermal treatment (detection limit 2%). In dust-fractions (particles smaller than 100 µm), however, the amounts of chrysotile could be increased by about 22%. Two explanations may be valid for this effect; either an appreciable amount of amorphous substances was dissolved, and/or additional chrysotile was formed. As relatively high contents of accessory minerals were unexpectedly resistent to dissolution, the above mentioned increase of chrysotile concentrations cannot be correlated with this fact. Concerning the accessory minerals, dolomite in Zidani fibre was hydrothermally reduced by a factor >6 (0.3% still remained). By simple exposure to water brucite can be removed from the cleaned Advocate fibre. 25% to 35% of the contaminating calcium present was dissolved, from all kinds of fibres, when treated hydrothermally.

TABLE 4

ZETA-POTENTIALS OF CHRYSOTILES (mV)

origin	no cleaning	special cleaning		
	blank	blank	treated in H_2O	
			normal conditions	hydrothermal
Advocate	+54	+48	+53	+52
Balangero	+24	+26	+28	+10
" + 1% SiO_2			+23	-26
Zidani	+18	+17	-13	-31
" + 1% brucite			± 0	-26

Table 4 illustrates the influence of hydrothermal treatment on the electrical potentials of the fibre surfaces. It is surprising that the surface charge of the Advocate fibres could not be changed. A complex hydrated magnesium layer surrounding the fibres may be the explanation; this layer seems to be much more resistent to hydrothermal influence than brucite. The surface of Balangero fibres with medium zeta-potentials is more sensitive to hydrothermal conditions, whereas the surface charge of Zidani fibres with low zeta-potentials changes its sign even in water under normal conditions. A reversal of the sign of the surface charge can be produced with the Balangero fibres when silica is added (Table 4).

As a result of our experiments concerning adsorption of brucite on Zidani fibres, we suggest that experiments concerning the chemical adsorption of organic polymers on unsaturated silanol groups of chrysotile, as described by Cossette and Lalancette (1975) would be particularly successful with hydrothermally treated Zidani fibres.

The behaviour of the surface as already described is most important in regard to the contact of the various fibres with the basic medium of the cement slurry and, therefore, the mechanical qualities can be correlated with out observations of the zetapotentials. By hydrothermal treatment filtrability and strength (determined in the Company's labs according to a modified F.V.T. test) were improved for the Advocate fibre, but not for Balangero and Zidani fibres. The results of the more detailed investigation of the Advocate fibre with respect to filtrability and strength are compiled in the diagram of Figure 6. Filtrability is strongly enhanced by additives (1%) of silica, brucite and alumina at higher temperatures (200°C), whereas the strength was remarkably reduced if fibres were treated in diluted ammonia.

Liquid Phase

The behaviour of *magnesium in solution* under hydrothermal conditions is described in the following: under normal conditions (at 1 kp cm^{-2} and 20°C, abbreviated 1/20) $7.7 \cdot 10^{-5}$ mole/1 MgO from AMC, $2.9 \cdot 10^{-5}$ mole/1 from BMC, and $5.0 \cdot 10^{-5}$ mole/1 from ZMC were dissolved after one day. Equilibrium was already reached in this time and maintained until the 20th day. At the higher temperature of 80°C the dissolution of magnesium was strongly enhanced: after 20 days the amounts had increased by factors of 2.9, 2.6, and 1.5 for AMC, BMC and ZMC, respectively. Contaminating minerals containing magnesium, such as brucite were increasingly dissolved at higher temperatures. The amount of dissolved magnesium decreased with increasing pressure. Magnesium ions are prevented from moving from the fibre surface into solution at pressures >50 kp cm^{-2} and temperatures >100°C.

The *dissolved silica* in aqueous phase behaved differently for the three types of chrysotile fibres: $5.7 \cdot 10^{-5}$ mole/1 $(SiO_2)_{aq}$ were dissolved in suspensions of *ZMC* reaching solubility equilibrium at 1/20 after one day. Increasing temperature caused higher solubility of $(SiO_2)_{aq}$ whereas pressure had almost no influence. As the silicon layers cover a great area of the surface of the Zidani fibre, continuous dissolution of silicon from the surface is guaranteed; it cannot be excluded, however, that amorphous silica originating from the inner space of the tubular fibres is being dissolved, too. $2 \cdot 10^{-5}$ mole/1 dissolved silica were determined in the suspensions of *BMC* under normal conditions; equilibrium was reached after one day. At 100°C the solubility increased by a factor of 4. Further

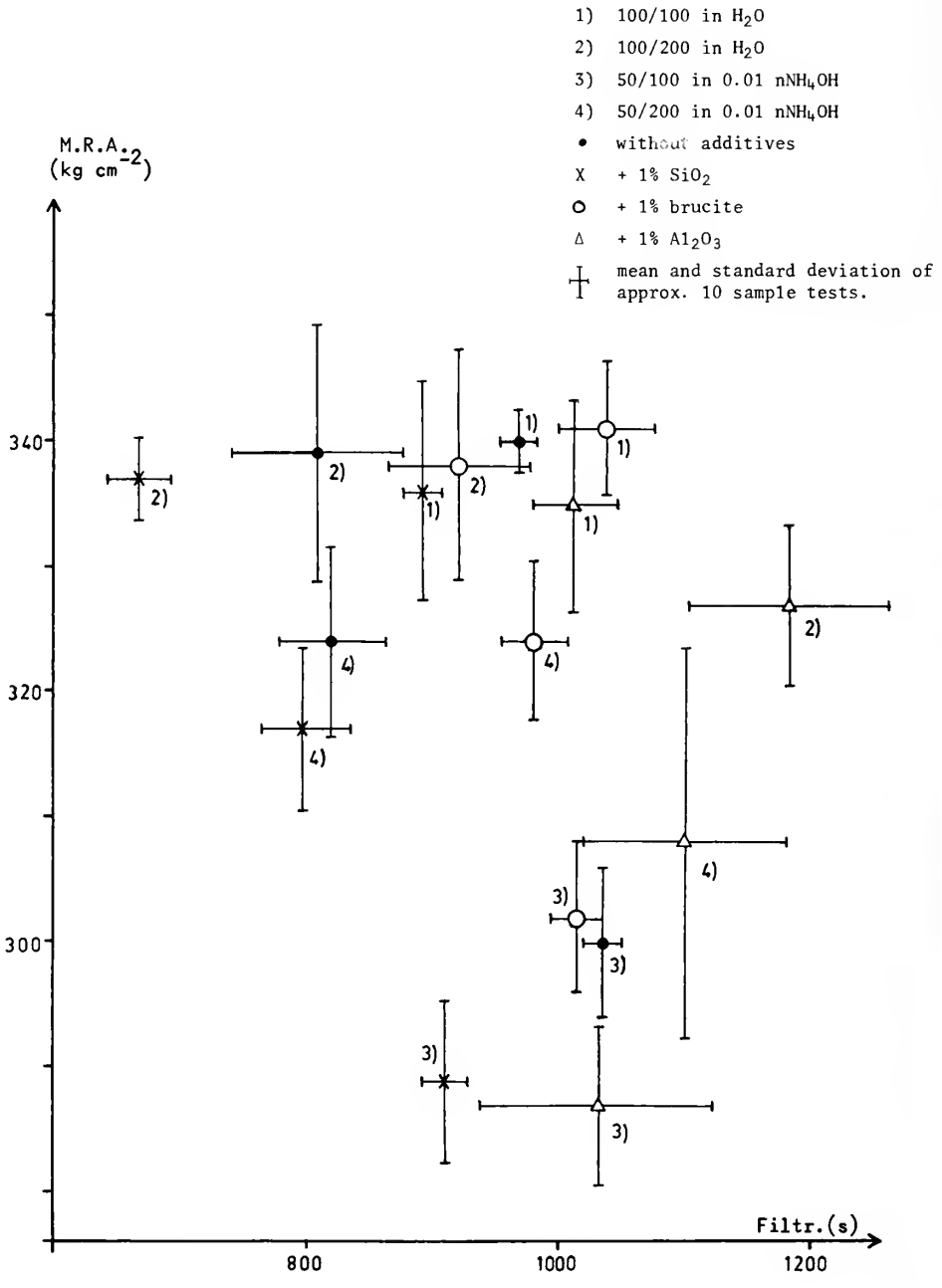

Figure 6. Filtrability and strength of asbestos cement cakes Advocate fibre after treatment.

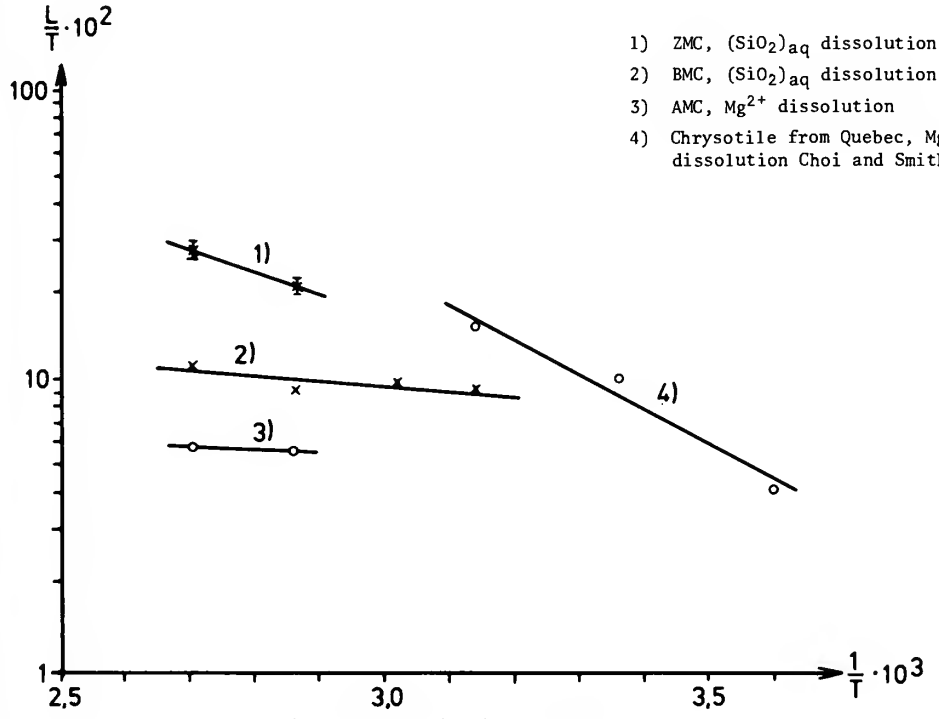

Figure 7. Activation Energy Plot

increase of the P/T-conditions did not noticeably change the amounts of dissolved SiO_2. In the case of *AMC* a distinct decrease of $(SiO_2)_{aq}$ in the solution was generally observed from the first to the twentieth day, i.e. by a factor of 2.3 at 1/20 up to >10 at 300/200. This indicates that the silicon layer in Advocate chrysotile exposes a relatively small area of contact to water where a local saturation of $(SiO_2)_{aq}$ is instantly reached.

The pH showed almost constant values in the range of 6.5 to 8.0 during all the runs. In the filtrates the conductances were always correlated with the concentrations of the ions.

THERMODYNAMIC DATA

In principle there are two possible mechanisms responsible for dissolution of serpentine: solid state diffusion and/or dissociation of the mineral surface. Luce et al. (1972) showed for lizardite that dissolution is a function of time squared; strong acid causes a linear relationship. Dissolution of *ground chrysotile* is affected only by dissociation of the large "brucite-like" surface of the fibres. After the first minutes of contact with water hydroxyl groups of chrysotile are already dissolved and final pH is reached. The dissolution of Mg^{2+} is proportional to the temperature and is terminated within the first hour at $T>45^{\circ}C$. In the following the reactions on the surface of chrysotile equilibrate by readsorption of $MgOH^{+}$ and $Mg(H_2O)_6^{2+}$ (Choi and Smith 1972). Dissolution of ground chrysotile in water is incongruent for short periods (minutes to hours) and congruent for long periods (days to months).

The simplified description given above cannot be fully accepted for the dissolution processes of *unground fibres*. The latter showed solubility equilibria of the major elements only at 1/20 for BMC and P = 1 kp cm^{-2} and $T \leq 100^{\circ}C$ for ZMC for one to twenty days. Within the first day no equilibria were detected for any kind of fibre. A stationary dissolution process under hydrothermal conditions could not be observed in any run. In order to get data suitable for thermodynamic calculations the above mentioned fluctuations and trends were averaged or extrapolated.

Activation energies of dissolution for the main constituents of unground chrysotile in water were calculated from the time-dependent solubility plots, assuming a first order reaction. By plotting log [Rate (=$slope_{max}$)/T] versus 1/T, as it is shown on Figure 7, the energy of activation for the magnesium ions and the silica complexes in water were determined by the slopes of the graphs. For magnesium dissolution from AMC 6.4 kcal/mole (Choi and Smith (1972) found 5.5 kcal/mole), and for silica dissolution from BMC and ZMC 11.25 and 8.5 $\pm$3.7 kcal/mole were calculated, respectively. If these values are compared with that of 5.3 kcal/mole for self-diffusion of water molecules in water (Glasstone et al. 1941), it is clear that the dominant process of dissolution of unground chrysotile is the diffusion of magnesium and silicon from the surface of the fibre into the suspending medium.

TABLE 5

GIBBS FREE ENERGY $-\Delta G_f^o$ (kcal/mole) FOR CHRYSOTILE AT 25°C, 1 ATM.

author	Luce (1966)		King et al. (1967)	Hostetler and Christ (1968)	Wildman et al. (1971)	Bricker et al. (1973)	Chernosky (1973)	Hirner (1976)		
origin	New Idria	synth. chrys.	New Idria	New Idria synth. chrys.	New Idria Henneke Dubakella	New Idria synth. chrys.	synth. chrys.	AMC	BMC	ZMC
sample preparation			grinding	grinding	crushed serpentinite	grinding	"free of amorphous material"	manufactured fibres >100 µm		
method	equilibrium in H_2O		calorimetry	equilibrium in H_2O		stability conditions		equilibrium in H_2O		
temp. of exp.	25°C		25°C	90°C	25°C			80°C		
$-\Delta G_f^o$ (25°C)	963,5±0,5	957	964,75	964,92	962,9±3	962,08 ±0,68	963,69 ±0,31	965,48 ±0,44	964,09 ±0,29	962,97 ±0,57

The activity product constants K_{Chr} and the Gibbs free energy ΔG_f^o were determined with the aid of the activity values for Mg^{2+}, $(SiO_2)_{aq}$ and pH, according to the elementary equations:

$$\underbrace{Mg_3Si_2O_5(OH)_4 + 5H_2O}_{a} \rightleftharpoons \underbrace{3Mg^{2+} + 6OH^- + 2H_4SiO_4}_{b}$$

$$K_{Chr} = [Mg^{2+}]^3 \quad [OH^-]^6 \quad [H_4SiO_4]^2$$

$$\Delta G^o = - RT \ln K_{Chr} = (\Delta G_f^o)_b - (\Delta G_f^o)_a$$

with a = reactants and b = products.

The Gibbs free energy was derived from the experiments in the oilbath at 80°C using thermodynamic data from King et al. (1967) and Hostetler and Christ (1968). In Table 5 our results are compared with those of other authors; of course, the data were recalculated for standard conditions.

In general, the values for the Gibbs free energies of fibres of different localities may differ by 2 to 3 kcal/mole. The Advocate fibre is more stable from the standpoint of energy than of Zidani; the one from Balangero holds a mid-position. King et al. (1967) and Hostetler and Christ (1968) found for New Idria chrysotile a value which is exactly the mean between our values for AMC and BMC. The value of Bricker et al (1973) seems to be too high for an average which can be explained by the fact that he used in his calculation a value for talc which is still under discussion (Chernosky 1973).

CONCLUSIONS

1) By a mechanical cleaning process of chrysotile fibres all other serpentine minerals are removed from clino-chrysotile.

2) Clinochrysotiles from Advocate and Balangero are resistant to hydrothermal treatment; but in those from Zidani antigorite is formed.

3) The dust-fraction contains significantly more chrysotile if treated hydrothermally.

4) With the exception of magnetite accessory minerals are removed by mechanical cleaning and hydrothermal treatment from the fibre, but not from the dust-fraction. Contaminating minerals, which are epitactically intergrown with fibres, are hydrothermally dissolved.

5) Some minor and trace elements - such as aluminium - are located in the chrysotile structure and their amounts are neither mechanically nor hydrothermally influenced.

6) The Gibbs free energy of the three kinds of fibres investigated differ by 2.5 kcal/mole. The calculated activation energies for the dissolution of magnesium and silicon demonstrate that these processes are typical of diffusion from the fibre surface into solution.

7) The surface of chrysotile fibres is of importance to their mechanical properties. Fibres with high positive surface charges show good mechanical qualities and are hydrothermally resistant. Fibres with low positive surface charges, however, change their potentials to negative values and are able to absorb positively charged complexes.

Summarizing: chrysotile fibres with high surface charge, such as Advocate, are suitable for the manufacture of asbestos cement products; fibres with low surface potentials, such as Zidani, should be more advantageous for the development of composite materials.

ACKNOWLEDGEMENTS

We are grateful to Eternit S.A., Belgium and its director A. Gosseye for financial support and Professor P. Ney, University of Cologne for intrumental help.

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(Manuscript received 21.12.1976)
(Manuscript received in final form 10.5.1977)

Journal and Proceedings, Royal Society of New South Wales, Vol. 110, pp. 111–116, 1977

Textures of the Carboniferous Ignimbrites in the Hunter Valley, N.S.W.

B. Nashar and A. T. Brakel

ABSTRACT. Rocks of the Carboniferous calc-alkaline volcanic series in the Hunter Valley, New South Wales, possess well-defined eutaxitic devitrification and possibly vapour-phase textures and show varying degrees of welding and compaction. The devitrification and vapour-phase textures comprise axiolitic, spherulitic, granular and granophyric forms. The eutaxitic textures suggest that the ignimbrites were emplaced by an ash-flow mechanism with welding commencing after the flow came to rest accompanied by compaction due to the overlying lithostatic load.

INTRODUCTION

Occurring within the Hunter Valley is a petrographic province of Carboniferous volcanic rocks of the andesite-dacite-rhyodacite - rhyolite association, first described in a series of papers by Osborne (1922a, 1922b, 1925, 1927, 1928a, 1928b), Browne (1927) and Scott (1948). As indicated in Figure 1 the Carboniferous rocks crop out in a belt which extends beyond the Hunter Valley in a north-westerly direction between Tamworth and Gunnedah to east of Moree. The volcanics were developed extensively and regularly throughout the Carboniferous System from Upper Visean to Upper Stephanian time. Scott (1948) and Osborne (1950) first recognised some of these rocks as ignimbrites.

ROCK TYPES AND MINERALOGICAL COMPOSITION

The rocks range in composition from pyroxene andesite (approx. 59% SiO_2) to rhyolitic ignimbrite (approx. 78% SiO_2). The pyroxene andesites are the only rocks which can be identified as normal lavas. The others are either ignimbrites or devitrified rock whose original texture has been obscured.

Because the magmatic history of the rocks does not favour equilibrium between phenocrysts and groundmass the mineralogical composition and proportion of the phenocrysts do not reflect the chemical composition. Quite acid rocks contain plagioclase and ferromagnesian phenocrysts expected from a more basic magma. The acid components are 'hidden' in the groundmass. On the basis of chemical analyses Nguyen (1976) has termed the rocks pyroxene andesite, hornblende dacitic ignimbrite, rhyodacitic ignimbrite and rhyolitic ignimbrite. Their phenocryst assemblage and percentage and groundmass percentage are given in Table 1.

The term *ignimbrite* is used by the authors in the same way as *ash flow tuff* is used by Ross and Smith (1961). The term includes *welded tuff* because, as will be seen below, the ash flow tuff may be unwelded, partially welded or densely welded. (Smith, 1960).

MODE OF OCCURRENCE

The Carboniferous ignimbrites in the Hunter Valley occur usually in lithological units ranging

TABLE 1

PHENOCRYST AND GROUNDMASS PERCENTAGE

ROCK TYPES	PHENOCRYSTS								GROUND MASS
	Qtz	K-Feld.	Plag.	Biot.	Hble	Hyp.	Aug.	Fe-Ti Oxides	
Rhyolitic ignimbrite	2	5	2	2					89
Rhyodacitic ignimbrite	6	4	10	3					77
Hornblende dacitic ignimbrite	rare		27	2	6	3	rare	2	60
Pyroxene andesite			31			7	5	3	54

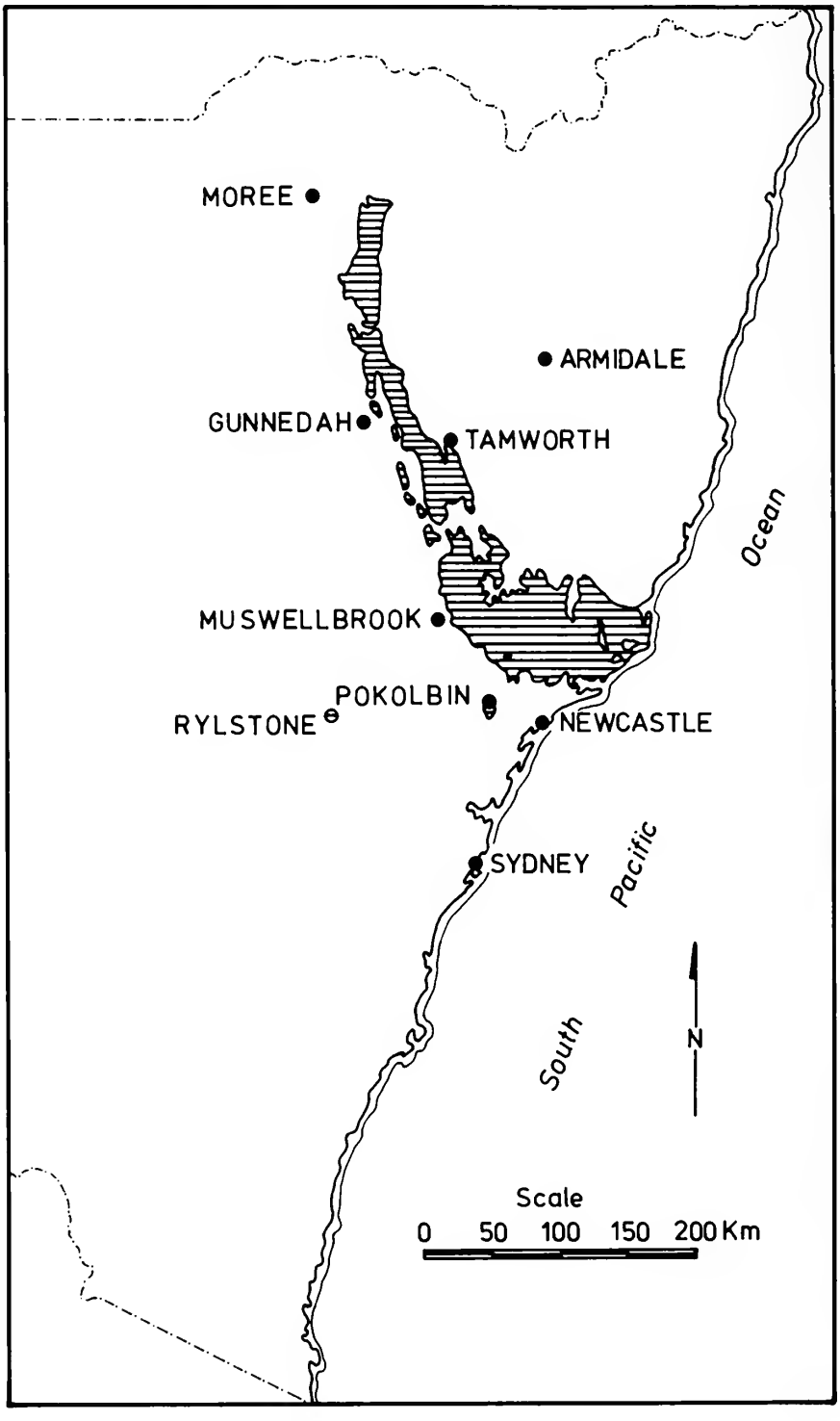


Fig. 1. Distribution in New South Wales of Carboniferous rocks in which ignimbrites occur

in thickness from a few metres to about 100m but some are greater. For example, the Mt Bright Rhyolitic Ignimbrite Member near Pokolbin (Brakel, 1973) has been estimated to be about 460m thick and the Paterson Volcanics at Mt Tangorin 310m (Slee, 1968). The aerial extent also varies. Some, such as the Mirannie Volcanic Member and Paterson Volcanics, cover a considerable area and have been used as marker units for a distance of up to 65km. Some units comprise one ash flow while others are multiple and comprise two or three.

Terminations of ignimbrite units have been observed and in all instances the rock grades into an agglomerate in which phenoclasts of rounded volcanic material in places exceed by volume the proportion of matrix. Tuffs and tuff breccias are associated with the agglomerate. The units become thinner until they lens out.

TEXTURES

In handspecimen the rocks are porphyritic. The phenocrysts average about 4mm in size and are set in either a lithic or vitroclastic groundmass which is generally quartzo-feldspathic in composition wherever devitrification has occurred. The plagioclase phenocrysts in the lighter coloured rocks are often pink in colour. The rhyolitic ignimbrites often contain abundant pumiceous fragments (Plate IA).

The lithoidal varieties vary in colour depending upon the degree of alteration. The more acid rocks are buff, pink, cream or white but when fresh are usually dark grey as are the andesites. Occasionally, the ignimbrite may be light to dark green in colour due to the presence of secondary celadonite in the matrix. The vitric varieties are black, or greenish black, pitchstones and are often cross-cut by dark red devitrified and haematitized layers. These rocks, when weathered, take on a brick red lithoidal appearance.

Under the microscope, phenocrysts, particularly of quartz, are usually seen to be resorbed and embayed and it is not uncommon for those of biotite and hornblende to be resorbed and their former presence marked by granules of magnetite. The abundance of phenocrysts varies from 5 to 55%.

The groundmass of all rock types except the pyroxene andesites is usually eutaxitic and examples of poorly welded, moderately welded and strongly welded ash flow tuffs abound (Plate IB, C, D, E, F).

The shapes of the shards in thin section are mostly cuspate but Y, U or C and O shapes are common. The shape depends upon the degree of initial fragmentation, subsequent compaction of the ash flow tuff and plane of section. In the loosely compacted rocks, complete bubble shapes and bubbles in various stages of fragmentation can be clearly seen (Plate IB, C).

In many cases compaction has resulted in the shards being compressed against or even moulded around the phenocrysts (Plate IF).

Pumice and lithic fragments of variable size (up to 25mm) are common and these, too, are frequently elongated and aligned parallel with the shards. Often, the ends of the pumice fragments are frayed.

Devitrification of shards and pumice is commonly developed. The most usual forms are axiolitic (Plate IIA), granular (Plate IIB) and spherulitic. The crystallization within the spherulitic form is of three types. The first comprises radiating fibres. In the ignimbrites it is sometimes difficult to discern the shape of the spherules when viewed in plane light but when the nicols are crossed the radiating fibres are seen to cut across the shards. The second, although resembling the radiating type in ordinary light (Plate IIE) is seen to have a granular texture when observed between crossed nicols (Plate IIF) while the third, again indistinguishable from the first two types in plane light (Plate IIC) reveals granophyric texture between crossed nicols (Plate IID). The latter two types occur in the rhyolitic lavas and there is a possibility that they may be the result of vapour-phase crystallization rather than the products of devitrification.

Vapour-phase crystallization has been described by Brakel (1967), Marchoni (1968) and Frater (1970). This consists of silica mineralization in cavities in the Y- and O-shaped shards and small accumulations within what are believed to be pore spaces between gas bubbles. The quartz granules are coarser than those of the devitrification products. Whether these and/or the spherules in the rhyolites are vapour-phase phenomena is uncertain. If they are, the original form of silica would probably have been cristobalite and/or tridymite which has inverted to quartz.

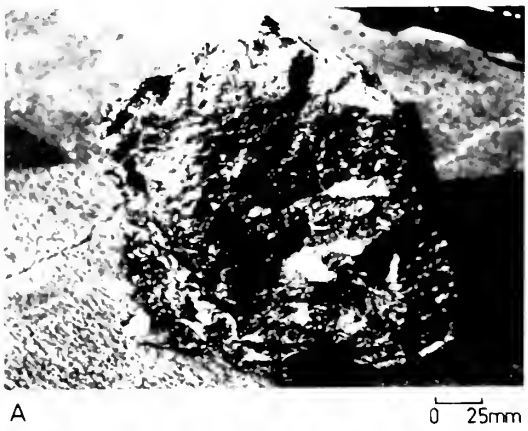
Granophyric crystallization has been observed in fine-grained Carboniferous acid rocks from the Gloucester District but no trace of eutaxitic texture is evident in them. Whether their texture represents a coarser than usual devitrification product or primary crystallization from an intrusive melt could not be determined.

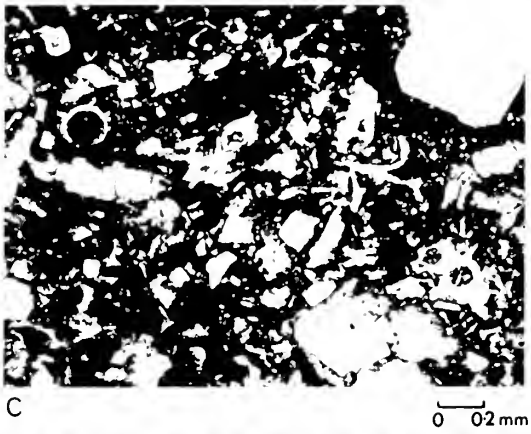
SIGNIFICANCE OF THE TEXTURES

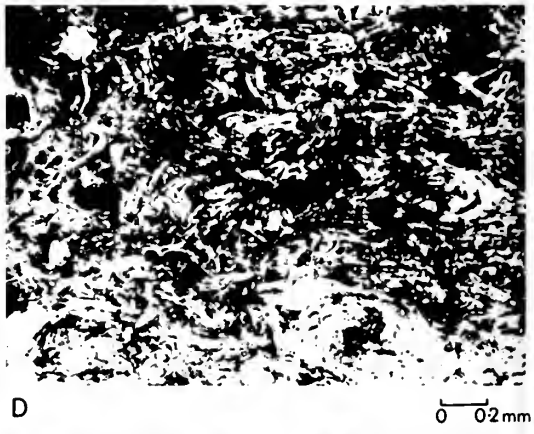
In spite of their age, these Carboniferous lithoidal and vitric volcanic rocks possess well-defined eutaxitic and devitrification textures typical of younger ignimbrites found and described elsewhere.

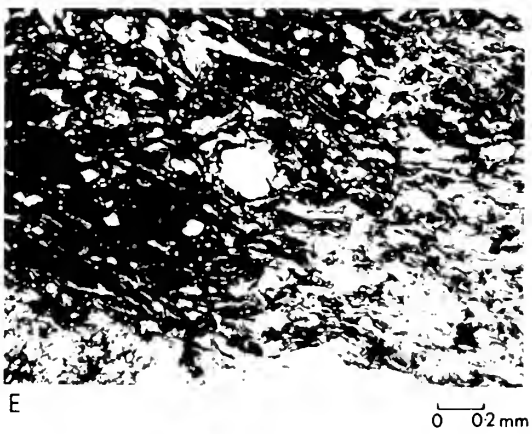
According to Smith (1960), ignimbrites have been emplaced as hot avalanche-type masses, which probably contained hot gases, and therefore may have been to a greater or less extent autoexplosive. Welding commenced after the flow came to rest and was accompanied by compaction due to the overlying lithostatic load, resulting in shards of glass (or devitrified glass) and fragments of pumice and rock being aligned in a parallel arrangement as indicated in Plate IA, D, E, F.

Using Smith's (1960) model of zones of welding which requires zones of no welding at the base and top of the cooling unit and zones of partial welding separating these from a central zone of dense welding, the degree of welding of the shards indicates the position of the specimen within a cooling unit. Thus, not only the zonal pattern within the









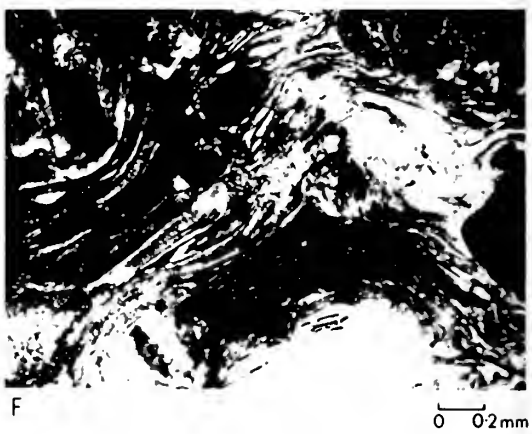
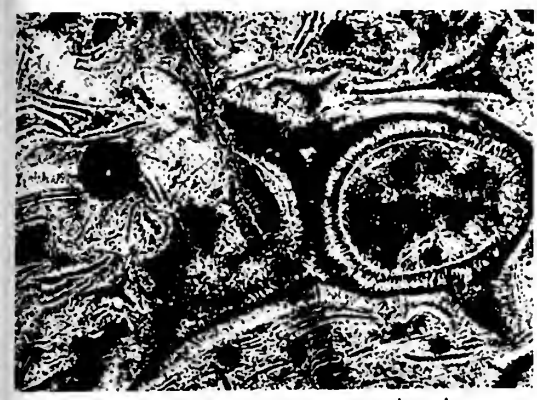
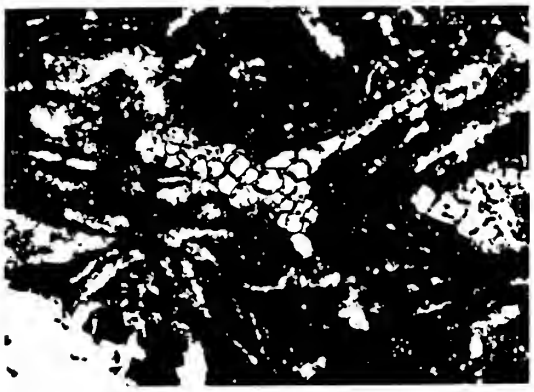
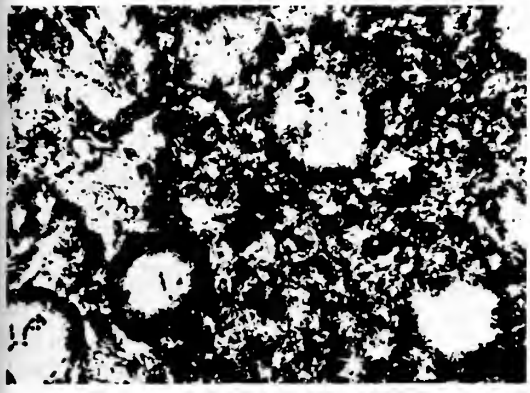


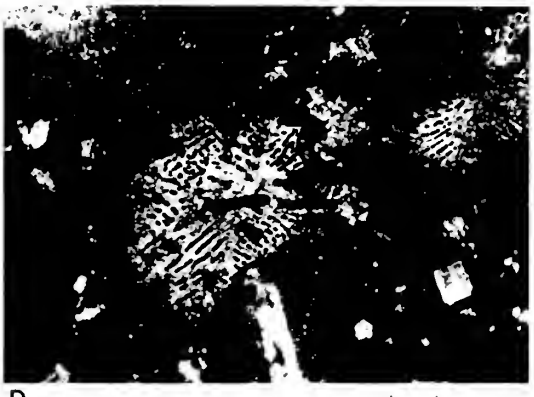
PLATE I

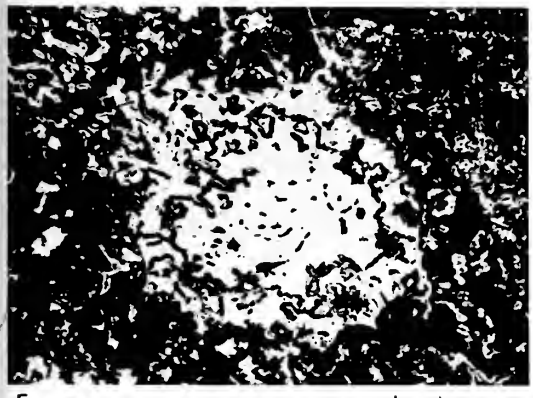
A Pumiceous fragments in rhyolitic ignimbrite (Scone 310975)
B Non welded rhyodacitic ignimbrite. Plane light (Camberwell 352992)
C Poorly welded rhyodacitic ignimbrite showing various shapes of shards. Plane light (Camberwell 352992)
D Moderately welded rhyodacitic ignimbrite. Plane light (Camberwell 171982)
E Strongly welded rhyodacitic ignimbrite. Plane light (Camberwell 101971)
F Very strongly welded rhyodacitic ignimbrite showing compaction of shards around phenocrysts. Plane light (Camberwell 258985)











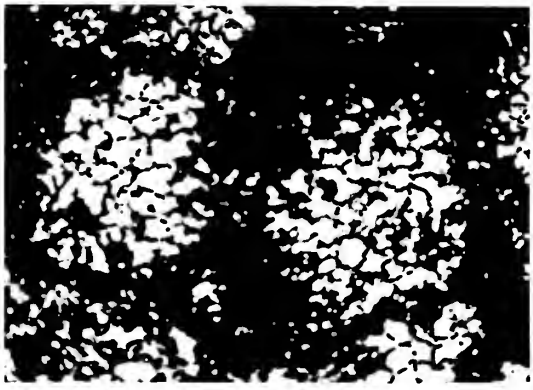


PLATE II

A Rhyolitic ignimbrite showing axiolitic crystallization of the shards. Crossed nicols (Cessnock 292417)
B Rhyolitic ignimbrite showing granulitic crystallization of the shards. Crossed nicols (Cessnock 292417)
C Spherulitic crystallization within rhyolite. Plane light (Dungog 940108)
D Granophyric crystallization within the spherules depicted in C. Crossed nicols
E Spherulitic crystallization within rhyolite. Plane light (Dungog 940108)
F Granulitic crystallization within the spherules depicted in E. Crossed nicols

unit may be determined but also the cooling units themselves may be defined. To give two examples, Brakel (1973) has recorded the thick Mt Bright Rhyolitic Ignimbrite Member near Pokolbin which shows a gradation from loosely welded texture at its base to extreme welding at its top. At the top of the unit is an unconformity, indicating that the upper, less strongly welded zones have probably been removed by erosion. Frater (1970) has successfully defined welding zones in ash flow tuffs in the Rouchel Brook-Back Creek Area according to Smith's model.

The eutaxitic texture of most of the rocks suggests that they were emplaced by an ash-flow mechanism. The ash-flows, similar to *nuées ardentes*, are regarded as mixtures of gas-emitting shards and pumice shreds, with some lithic fragments. At the base and top of the flows, where the opportunity for the loss of heat and volatiles was greatest, the shards became rigid soon after being formed and consequently the material deposited was unwelded or poorly welded. In the centre of the ash-flows, because of the higher concentration of volatiles and heat, the shards and pumice fragments were still in a plastic state when the flows came to rest, and welding took place aided by lithostatic load.

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(Manuscript received 10.5.1977)

Journal and Proceedings, Royal Society of New South Wales, Vol. 110, pp. 117–138, 1977

Petrogenetic Aspects of Some Alkali Volcanic Rocks*

J. F. G. WILKINSON

ABSTRACT. The roles of low- and high-pressure fractional crystallization are examined and reservations expressed concerning their validity as controls in the genesis of certain alkaline volcanics. These reservations arise largely because of very limited data documenting the existence of the appropriate complementary crystal extracts required by fractional crystallization models. Low-pressure fractionation trends in alkali feldspar-bearing olivine nephelinites from the Inverell area, New South Wales, are defined by the compositions of schlieren and leucocratic veinlets. These indicate the capacity of olivine nephelinites to ultimately yield phonolitic derivatives via transitional malignitic compositions. The vitric residuum in a highly undersaturated vitrophyric phonolite from the Dunedin Volcano, East Otago, is mildly peralkaline. However, peralkalinity in potential derivatives of such highly undersaturated *ac*-free salic parents, crystallizing nepheline before Ca-bearing alkali feldspars, is largely suppressed until the parent melts experience extensive crystallization on or close to the respective nepheline-alkali feldspar field boundaries.

The efficacy of high-pressure fractionation (P > 10 kb), largely controlled by kaersutitic amphibole and lesser olivine and clinopyroxene, in the genesis of certain 'evolved' (but nevertheless displaying relatively high 100 Mg/Mg+Fe ratios) alkaline volcanics (hawaiites, nepheline mugearites, nepheline benmoreites, etc.) containing Cr-diopside lherzolite xenoliths is examined with particular reference to specific eruptives from the Newer Volcanics of Victoria. This model finds little support in the (relative) abundances or frequencies of occurrence of the phases (megacrysts) comprising the alleged high-pressure crystal extracts. It is proposed that at least some 'evolved' high-pressure alkaline volcanics may be the products of direct partial melting of relatively iron-rich lherzolites (100 Mg/Mg+Fe ~ 80-86).

INTRODUCTION

It is an honour indeed to be invited by the Royal Society of New South Wales to be their Clarke Memorial Lecturer. In the 1975 Clarke Lecture my old friend K.S.W. Campbell spelt out with strong conviction that W.B. Clarke "really loved" fossils. I am unable to state with the same confidence whether W.B. Clarke had the same feelings towards alkaline rocks but I hope, however, that he would have had at least a certain fondness for them.

Fractional crystallization, the central theme of the Lecture, is the genetic control most commonly invoked to explain the diversity of lava types (particularly those more evolved than basalt) in anorogenic volcanic assemblages. It becomes a potentially viable control on the intervention of any mechanical process which removes and inhibits equilibration between early-formed crystals and their parent melts. Low-pressure fractional crystallization trends in alkaline melts can be identified and evaluated by studies of differentiated intrusives (commonly sill-like and relatively restricted in thickness and lateral extent), schlieren, and vitric residua in extrusives. Although these studies may delineate the character of potential low-pressure differentiates their viability in explaining the spectrum of compositions within a specific volcanic province is nevertheless subject to a number of constraints. For example, it is not merely sufficient to demonstrate chemical coherence and reasonable materials-balance relations between assumed derivatives, parent liquids and potential (zoned) crystal extracts (the liquidus or near-liquidus phenocrysts in the parents). Within the volcanic province as a whole, there should be at least some tangible evidence of the fundamental corequisite to a fractional crystallization model involving multicomponent melts, namely the complementary crystal fraction(s) to each liquid derivative (= evolved aphyric lavas) generated during an event which is often interpreted as both protracted and complicated. The same constraint, which will be subsequently discussed in more detail, is equally applicable to genetic models based on fractional crystallization controls at high pressures.

Coombs and Wilkinson (1969) have summarised low-pressure fractionation data for a spectrum of alkaline liquids, differing in Na/K and Fe/Mg ratios and levels of undersaturation (alkali basaltic to basanitic). The reader is referred to this paper for a summary of low-pressure fractionation trends displayed by differentiated alkaline melts, intrusive and extrusive. However, there were no data at that time documenting the low-pressure fractionation behaviour of olivine nephelinite - it is, admittedly, either absent or else only a minor component in most alkaline volcanic provinces but olivine nephelinites nevertheless may occur on an essentially semi-regional scale, as in the East African rift system. Low-pressure fractionation trends in a representative from the felsic end of the highly undersaturated alkaline volcanic spectrum (a vitrophyric phonolite) will also be examined.

* *The Clarke Memorial Lecture, delivered before the Royal Society of New South Wales, 14th July, 1977.*

TABLE 1
ANALYSES OF OLIVINE NEPHELINITE, SCHLIEREN, AND SOME CONSTITUTENT MINERALS

Analysis number	1H	2H	1N	2N	3	4	5	6
SiO_2	41.92	46.10	43.8	44.1	-	-	52.1	51.7
TiO_2	2.29	1.84	-	-	22.4	18.3	1.04	2.01
Al_2O_3	13.29	18.10	33.5	33.2	0.46	0.95	1.81	0.80
Cr_2O_3	-	-	-	-	0.46	0.13	-	-
Fe_2O_3	4.14	4.21	0.80	0.79	25.7	32.6	-	24.2
FeO	9.03	5.08	-	-	47.9	44.1	7.33[1]	1.8
MnO	0.23	0.17	-	-	0.77	0.93	-	0.32
MgO	8.60	3.39	-	-	1.90	1.79	13.7	2.82
CaO	10.25	6.62	0.14	0.20	0.20	-	22.9	5.61
Na_2O	4.43	5.80	16.8	16.7	-	-	0.57	10.3
K_2O	2.27	4.16	4.86	4.58	-	-	-	0.10
H_2O+	1.43	2.38	-	-	-	-	-	-
H_2O-	0.87	1.27	-	-	-	-	-	-
P_2O_5	1.39	0.99	-	-	-	-	-	-
Total	100.14	100.11	99.9	99.6	99.8	98.8	99.5	99.7

C.I.P.W. norms	1H	2H
Or	13.3	24.5
Ab	3.1	13.1
An	9.7	10.8
Ne	18.5	19.6
Di	25.8	12.5
Ol	13.6	4.2
Mt	6.0	6.0
Il	4.4	3.5
Ap	3.4	2.4
H_2O	2.3	3.6
Total	100.1	100.2
M^2	62.9	54.3
D.I.	34.9	57.2
Ne	57.7	46.7
Ks	21.7	24.3
Qz	20.6	29.0

[1]Total Fe reported as FeO. [2]M = 100 Mg/Mg+Fe^{2+}

1H Average host olivine nephelinite (4 analyses). Inverell 1:100,000, Sheet 9138, Series R651, grid ref. LN090040. Analyst G.I.Z. Kalocsai.

2H Average melanocratic schlieren (4 analyses). Analyst G.I.Z. Kalocsai.

1N Nepheline in olivine nephelinite 1H ($\Sigma Si+Al+Fe^{3+}$ = 16.05, based on 32 O; $Ne_{78.5}Ks_{16.6}Qz_{4.9}$ wt.%).

2N Nepheline in schlieren 2H ($\Sigma Si+Al+Fe^{3+}$ = 16.05, based on 32 O; $Ne_{78.6}Ks_{15.8}Qz_{5.6}$ wt.%).

3 Titanomagnetite in host olivine nephelinite (FeO and Fe_2O_3 calculated on ulvöspinel basis from microprobe analysis with total Fe expressed as FeO).

4 Titanomagnetite in schlieren (FeO and Fe_2O_3 calculated on ulvöspinel basis).

5 Titaniferous salite in host olivine nephelinite (Σxy = 2.00, based on 6 O; $Ca_{48.0}Mg_{40.0}Fe_{12.0}$ atom %).

6 Groundmass acmitic pyroxene in melanocratic schlieren (Σxy = 1.99, based on 6 O).

SOME LOW-PRESSURE FRACTIONATION TRENDS

Olivine Nephelinites and Associated Schlieren, Inverell Area, New South Wales

It is now reasonably well established that low-pressure fractionation of basanitic melts may ultimately yield phonolitic derivatives (*see* Coombs and Wilkinson, 1969, Fig. 4). Although deduced in a generalised way for some provinces (*e.g.* Saggerson and Williams, 1964; King, 1965) the nature and extent of fractionation trends of even more undersaturated mafic liquids, namely olivine nephelinites, have yet to be documented quantitatively. Certain olivine nephelinites in the Inverell area, north-eastern New South Wales, carry relatively more leucocratic schlieren (host-residuum field relations clearly indicate 'mother-daughter' consanguinity), thereby providing an opportunity to study the low-pressure derivatives from potentially plagioclase-free ultra-alkaline nephelinitic parents.

The most extensive development of ultra-alkaline extrusives in north-eastern New South Wales is located several kilometres west of the township of Inverell where the olivine nephelinites (as yet undated radiometrically) are the youngest eruptives in a volcanic province of diverse magmatic affinities. Cainozoic volcanic activity in this area commenced with olivine tholeiites and tholeiites of early Miocene age, soon followed by a mildly undersaturated sodic alkaline series, in which alkali olivine basalt, nepheline basanite and hawaiite are represented (Wilkinson, 1966; McDougall and Wilkinson, 1967; Duggan, 1972; Wilkinson and Duggan, 1973; Wellman and McDougall, 1974).

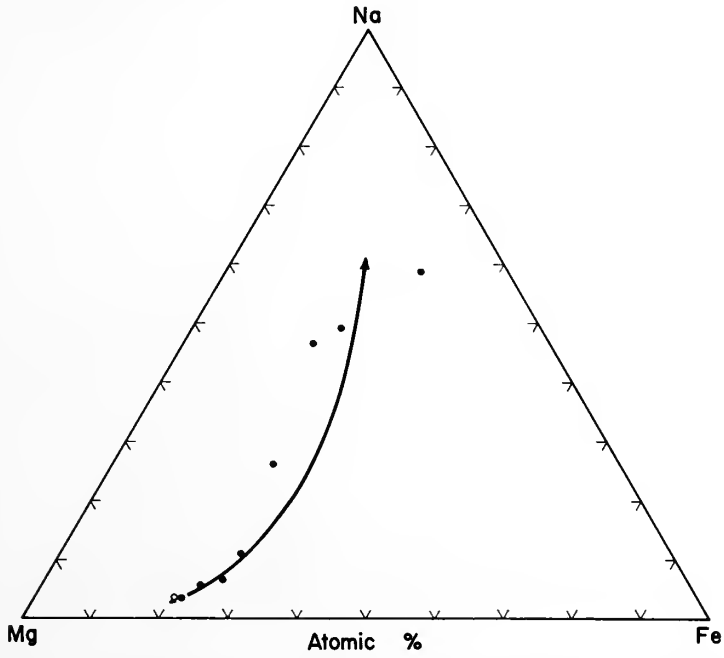

Fig. 1. Microprobe analyses of pyroxenes in Inverell olivine nephelinites and associated melanocratic schlieren. Total iron is determined as FeO, and Fe_2O_3 calculated by allotting equivalent molecular proportions of Fe_2O_3 to Na_2O. Open circle, average clinopyroxene composition in olivine nephelinite. Solid circles, clinopyroxenes in melanocratic schlieren.

The schlieren-bearing olivine nephelinites contain prominent phenocrysts of olivine in a fine-grained groundmass largely composed of prismatic titaniferous salite (average composition $Ca_{49}Mg_{39}Fe_{12}$; *cf.* Table 1, No. 5) which is often included in anhedral plates of nepheline ($Ne_{78}Ks_{17}Qz_5$; Table 1, No. 1N). Titanomagnetite (Table 1, No. 3; mol.% Fe_2TiO_4 = 62.4) is relatively abundant and minor soda sanidine ($Ab_{39}Or_{60}An_1$) and zeolite are groundmass constituents. The larger olivine phenocrysts are Mg-rich (*mg* = 85; *mg* = 100 Mg/Mg+Fe where Fe = total Fe calculated as FeO) but olivine phenocrysts, commonly zoned, generally have core compositions in the range *mg* = 78-70. The compositions of groundmass olivines average *mg* = 60, and are similar to the compositions of olivines (*mg* = 59) in the coarser-grained melanocratic schlieren. Rare Cr-diopside lherzolite xenoliths composed of olivine (*mg* = 90), aluminous orthopyroxene ($Ca_1Mg_{91}Fe_8$), aluminous chrome diopside and brown spinel are also present in the olivine nephelinite.

Contacts between the nephelinitic hosts and the coarser-grained 'mini-pegmatitic' schlieren (up to 5 cm wide) may be somewhat ill-defined in outcrop but thin-sections indicate a fairly abrupt change in relative average grainsize across contacts. Increases in felsic phases at the expense of olivine, clinopyroxene and titanomagnetite yield modal compositions for the wider (analysed) schlieren appropriate to (but somewhat more leucocratic than) malignite (Tröger, 1935). A fairly typical schlieren mode (vol.%) is olivine 2, clinopyroxene 15, nepheline 32, alkali feldspar 31, opaques 9, zeolite and mesostasis 11. The clinopyroxene in these particular schlieren is mainly a titaniferous salite, similar in composition to the clinopyroxene in the olivine nephelinite host (Fig. 1). However, some salite phenocrysts are now rimmed by green acmitic pyroxene and discrete crystals of acmite-rich clinopyroxene are also present in the groundmass (Table 1, No. 6; Fig. 1), sometimes in a reaction relationship with titanomagnetite. Figure 1 illustrates the solid solution between early-crystallized clinopyroxenes belonging to the Di-Hd series and later schlieren variants which display progressive Na Fe^{3+} → CaMg substitution. The clinopyroxene crystallization trend is thus similar to certain clinopyroxene trends in the Shonkin Sag laccolith, Montana (Nash and Wilkinson, 1970). Nepheline (Table 1, No. 2N) is euhedral towards alkali feldspar, an essentially An-free soda sanidine ($Ab_{37}Or_{63}$). Titanomagnetite (Table 1, No. 4; 51.6 mol.% Fe_2TiO_4) is depleted in TiO_2, Cr_2O_3 and MgO, and enriched in MnO, compared with titanomagnetites in the host olivine nephelinite. Areas of mesostasis are dominated by curved alkali feldspar microlites and zeolites.

The most evolved 'schlieren' form leucocratic

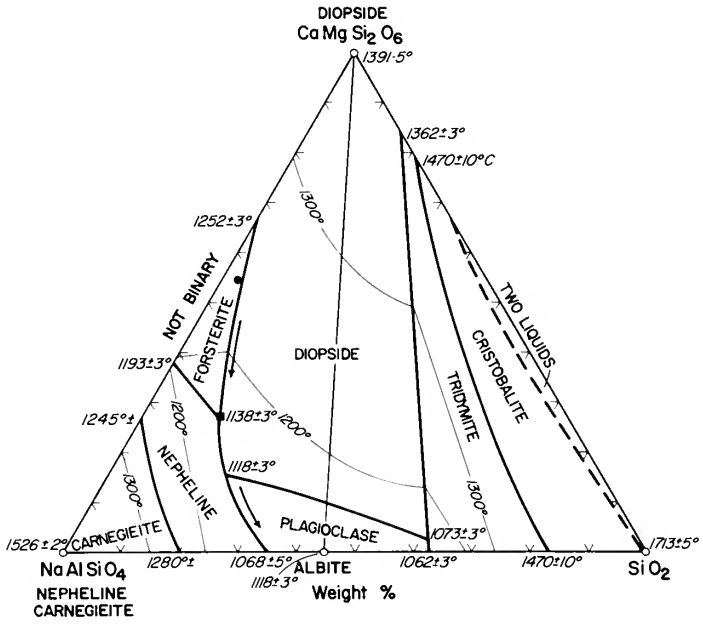

Fig. 2. Phase equilibrium diagram of the system nepheline-diopside-silica (Schairer and Yoder, 1960). The Inverell olivine nephelinites (Table 1, Analysis 1H) and associated melanocratic schlieren (Table 1, Analysis 2H) are indicated by a solid circle and solid square, respectively. Arrows indicate generalised low pressure fractionation trends of olivine nephelinites resulting from the successive separation of Fo-rich olivine, Ca-rich clinopyroxene and nepheline.

veinlets (2-5 mm wide) composed of alkali feldspar and nepheline (collectively these phases comprise more than 95% of individual veinlets, with alkali feldspar>>nepheline), plus minor Ca-rich pyroxene and zeolite (a potassic phillipsite). An average composition of the nepheline cores ($Ne_{80}Ks_{16}Qz_4$) is similar to the compositions of nephelines in the host olivine nephelinite and in melanocratic schlieren (Table 1) but the nephelines are zoned to rim compositions with either higher or lower Na/K ratios than the cores. The former trend is accompanied by enrichment in Si (*cf.* Brown, 1970). The sanidines in these highly leucocratic schlieren display differing degrees of enrichment in Ba. Average core compositions of optically clear sanidines essentially devoid of Ba ($Ab_{42}Or_{57}An_1$) are slightly less Or-rich than those in the host and in melanocratic schlieren but are zoned out to more Or-rich compositions ($Ab_{35}Or_{64}An_1$) (Fig. 3). Slightly turbid alkali feldspars are hyalophanes (with up to 5.2% BaO), the most Ba-rich variant having the composition $Cs_{13}Ab_{32}Or_{54}An_1$. The interpretation that these veins represent the most evolved residua in this association is consistent with the enrichment in Ba (x2) and Rb (x3) in the melanocratic schlieren, relative to the host nephelinite. Clinopyroxene remains a Ca-rich salite ($Ca_{47}Mg_{41}Fe_{12}$), and is thus similar in composition to the Ca-rich pyroxenes in the olivine nephelinite and the melanocratic schlieren.

Discussion

The host rocks conform modally with olivine nephelinite but despite low *ab* and moderate *an* (deriving in part from Al_2O_3 in clinopyroxene and titanomagnetite), they are not sufficiently undersaturated to permit the appearance of normative *lc* (compare the compositions of "average" olivine nephelinites listed by Nockolds (1954) and Le Maitre (1976) which contain 6.5 and 13.6% *lc*, respectively). However the Inverell olivine nephelinite (Table 1, No. 1H) is similar in composition to a slightly more Mg-rich example (M = 70.8; M = 100 Mg/Mg+Fe^{2+} when FeO and Fe_2O_3 are known) from Flinders Island, Australia. The 1 bar melting relations of this particular olivine nephelinite have been investigated by Tilley and Thompson (1972). Olivine appears on the liquidus at 1304°C and is followed in the crystallization interval by clinopyroxene (1150°C) and nepheline (1063°C). The Inverell olivine nephelinites display a similar order of crystallization and their low-pressure liquidus temperatures, as indicated by experimental data on lavas with comparable compositions, were probably close to 1200°C (Thompson, 1973). The chemistry of the clinopyroxene-rich schlieren (Table 1, No. 2H) is similar to that of the "average" malignite (Nockolds, 1954), the latter being relatively more sodic (Na/K = 3.3) and also mildly peralkaline (1.8 *ac*).

The field relations, modal compositions, order of crystallization of the host olivine nephelinites (D.I. = 34.9; D.I. = differentiation index, $\Sigma qz + ab + or + ne + lc$), and the respective phase chemistries indicate that the melanocratic pegmatoidal schlieren (D.I. = 57.2) and the leucocratic veinlets have been produced by low-pressure fractionation of Mg-rich olivine (becoming increasingly Fe-rich in successive fractions), Ca-rich clinopyroxene, and a Fe_2TiO_4-rich titanomagnetite. Olivine, clinopyroxene and titanomagnetite display the most extensive cryptic variation. In contrast the principal felsic phases (nepheline and alkali feldspar) retained relatively constant compositions. Nevertheless, fractionation of a sodic nepheline (Na/K = 5.3) from the host nephelinitic liquid (Na/K = 3.0) yielded malignitic residua which are relatively more K-rich (Na/K = 2.0) and which contain nephelines (of early crystallization) slightly enriched in Qz, a consequence of the increased silica activities of the residual liquids (Table 1).

The principal mineral phases in the olivine nephelinite-schlieren association define two (somewhat simplified) sub-systems; (i) the mafic assemblage olivine-Ca-rich clinopyroxene-titanomagnetite which collectively controlled schlieren decreases in TiO_2, total Fe, MgO, CaO and *M* values, and an increase in Al_2O_3; and (ii) the felsic assemblage nepheline-alkali feldspar, major phases in the Ab-Or-Ne-Ks quadrilateral of the residua system $NaAlSiO_4$-$KAlSiO_4$-SiO_2-(H_2O), which were largely responsible for alkali controls.

When projected (as a function of normative Ne, Di and Qz) in the Fe- and K-free system nepheline ($NaAlSiO_4$)-diopside ($CaMgSi_2O_6$)-silica (SiO_2) (Schairer and Yoder, 1960), the host olivine nephelinite ($Ne_{42.6}Di_{54.4}Qz_{3.0}$) plots in the forsterite field and the composition of the average malignitic schlieren ($Ne_{59.0}Di_{27.7}Qz_{13.3}$) falls close to the intersection of the olivine, diopside and nepheline phase boundaries (Fig. 2). This particular system appears to be the only synthetic system containing the assemblage forsterite + diopside + nepheline + liquid which approximates to olivine nephelinite. The order of crystallization of the natural liquids closely resembles that in the undersaturated portion of the simplified synthetic system where successive derivative liquids, following crystallization of forsterite, diopside, and finally nepheline, trend towards the lowest melting composition (1068°C) located on the $NaAlSiO_4$-SiO_2 join (the join diopside-albite in the anhydrous system is an equilibrium thermal divide). Residual liquids are thus albite- and nepheline-rich (with albite >>nepheline) and their analogues in the Inverell assemblages are represented by the highly leucocratic schlieren with somewhat comparable alkali feldspar-nepheline ratios. Probably as a result of relatively rapid cooling there are only limited petrographic data in the olivine nephelinites consistent with a reaction relation between olivine and liquid (a feature of the synthetic system) to yield diopside, indicated by discontinuous, localised salite rims to some olivine phenocrysts. Olivine would be expected to react out only under conditions of equilibrium crystallization.

In the residua system projection the salic components (less *an*) of the host olivine nephelinite plot in the nepheline field (Fig. 3) and successive liquids were displaced (in projection), following the initial crystallization of abundant nepheline, towards a natural nepheline-alkali feldspar field boundary. Nepheline was then joined in the crystallization interval by alkali feldspar. Evidence of peralkalinity in the malignitic schlieren is provided largely by the acmitic rims to salite phenocrysts and by the acmitic pyroxenes in their 'groundmasses'. Peralkalinity was thus restricted to relatively well-evolved stages in the crystallization histories of these schlieren (Na + K/Al = 0.78), largely following extensive crystallization of nepheline and an essentially An-free soda sanidine. The 'plagioclase effect' (Bowen, 1945), as a potential control in the development of peralkalinity, was therefore minimal.

Although it is not possible to obtain compositions of the most leucocratic veins (interpreted as the most evolved differentiates) by direct analysis, approximate compositions nevertheless may be derived indirectly from the compositions of their felsic phases, assuming that the compositions of the residual liquids which ultimately crystallized to alkali feldspar-nepheline assemblages fall on or close to the joins between these phases in the residua system. The salic components (less *an*) of the malignitic schlieren 2H approach (in projection) the low-temperature area in the undersaturated quadrilateral, determined experimentally under anhydrous and hydrous (P_{H_2O} = 1 kb) conditions (Fig. 3). More evolved residua generated largely by clinopyroxene fractionation must remain in this low-temperature area and hence retain a phonolitic character; they cannot evolve to relatively more saturated or more undersaturated compositions. The join between the Or-rich sanidine rims and the core compositions of the coexisting nephelines in leucocratic veinlets (complex nepheline zoning is disregarded) passes through compositions whose parameters in the low-temperature area in the residua system are approximately $Ne_{40}Ks_{30}Qz_{30}$ i.e. adjacent to but falling at more potassic compositions than the points R and T_m in Figure 3. These parameters may be recast to yield SiO_2 58.4, Al_2O_3 24.0, Na_2O 8.7, K_2O 8.9, which obviously define a potassic phonolitic composition. The Na/K ratio of this liquid (1.5) continues the trend of K-enrichment indicated by the melanocratic schlieren (Na/K = 2.1), compared with the olivine nephelinite (Na/K = 3.0), and now largely reflect controls resulting from the separation of major soda sanidine (Na/K = 0.78), less potassic than the liquid. Fractionation obviously took place at very low pressures. The compositions of their most evolved differentiates (devoid of modal leucite) actually plot well within the leucite field in the undersaturated quadrilateral of the residua system at 1 bar (Schairer, 1957). It thus appears that the field of leucite in the Ca-bearing residua system undergoes contraction even at very low pressures and that the minimum melting composition is displaced to more K-rich compositions, compared with the Ca-free system. Finally, it may also be noted that the subordinate phonolites associated with the nephelinite volcanic centres of eastern Uganda display relative enrichment in K (King, 1965).

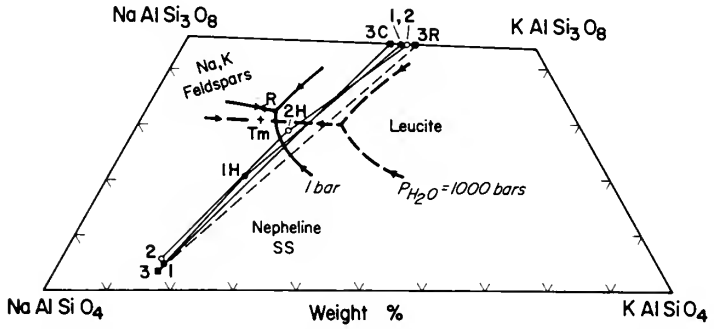

Fig. 3. Host olivine nephelinites (solid circle 1H) and melanocratic schlieren (open circle 2H) from the Inverell district, N.S.W., and their respective nephelines and alkali feldspars plotted in the undersaturated quadrilateral in the residua system (*see* Table 1). Analyses 3C and 3R (solid squares) denote core and rim compositions of soda sanidines in leucocratic veinlets (see text). The join 3-3R (dashes) between nepheline core composition 3 and the most Or-rich sanidine rims is also indicated. Portions of the nepheline-alkali feldspar boundary curves at 1 bar (solid lines; Schairer, 1957) and at P_{H_2O} = 1 kb (dashed lines; Hamilton and MacKenzie, 1965) are shown. The cross T_m = minimum on nepheline-alkali feldspar phase boundary at P_{H_2O} = 1 kb. R = ternary reaction point in the anhydrous system.

The low-pressure fractionation trends in the Inverell olivine nephelinites are similar, at least to compositions with D.I. ~ 50, to those in the melanocratic nepheline basanite (atlantite)-pegmatoid association at Omimi, East Otago (Coombs and Wilkinson, 1969). However the Inverell fractionation trends can be traced to much more evolved (phonolitic) compositions whose generation was at all times independent of plagioclase fractionation. At Omimi, calcic plagioclase is a prominent phase in the host basanites and potash oligoclase (zoned to soda sanidine) an important constituent of the associated pegmatoids.

Previous appraisals of low-pressure fractionation trends of olivine nephelinitic liquids have been based largely on broad field associations and not tested by the compositions of undoubted natural derivatives. The following fractionation sequences for natural assemblages have been proposed:-

(i) melanephelinite or olivine nephelinite → (basanite or tephrite) → phonolite (Wright, 1963; Spencer, 1969);

(ii) ankaratrite → (melanephelinite and nephelinite) → phonolite; (Saggerson and Williams, 1964);

(iii) melanephelinite-nephelinite → phonolite or trachyte (King, 1965);

(iv) olivine nephelinite → olivine nephelinites with increasing K/Na ratios → nepheline benmoreite → mafic phonolite (Sutherland, 1974).

Experimental data on the system Na_2O-Al_2O_3-Fe_2O_3-SiO_2 at 1 bar (Bailey and Schairer, 1966; Bailey, 1974) indicate that the quaternary reaction point ac + hem + ne + ab + liquid (the 'ijolite point') is linked via "malignite" on a univariant crystallization path ac + ne + ab + liquid to a quaternary eutectic equivalent to peralkaline phonolite.

The present study thus generally confirms the broad trends inferred from natural associations and experimental studies and indicates that phonolitic differentiates may derive from olivine nephelinite via transitional malignitic compositions. It also highlights some differences from the previous proposals. In the production of phonolitic differentiates from olivine nephelinites it is not necessary to assign a rôle to "transitional" plagioclase-bearing basanitic or tephritic types. Furthermore, the production of trachytic derivatives by fractional crystallization is highly unlikely. It must also be emphasized that on this occasion the volume of derivative phonolite is trivial (probably much less than 1% of that of the parental liquid) and that phonolitic derivatives are produced only when fractionation is well advanced. In this context it may be significant that phonolitic field associates of the Inverell olivine nephelinites have not yet been found.

It is not clear whether the present data can be applied directly to even more undersaturated *lc*-bearing olivine nephelinites fractionating at low pressures (the *lc* derives partly from the Ks component of nepheline). These olivine nephelinites may be highly sodic (Bailey, 1974, Table 2) and presumably the amount of alkali feldspar in such rocks may be minimal. However the relevant experimental data (Figs. 2, 3) indicate that alkali feldspar only appears as a significant phase at a late stage in the crystallization histories of successive residua and hence, via nepheline fractionation, should be stored initially in successive derivative liquids.

TABLE 2
ANALYSES OF VITROPHYRIC PHONOLITE, ITS RESIDUAL GLASS, AND PHENOCRYSTS

Analysis number	1R	1G	1N	1F	2
SiO_2	52.75	53.8	45.9	63.6	49.6
TiO_2	0.29	0.14	-	-	0.48
Al_2O_3	21.62	20.4	33.6	22.7	2.87
Fe_2O_3	0.96	1.05	0.27[1]	-	-
FeO	3.10	3.43	-	-	18.6[2]
MnO	0.13	0.10	-	-	0.58
MgO	0.15	0.10	-	-	5.74
CaO	2.04	1.58	1.62	3.28	20.5
Na_2O	10.38	10.1	16.0	7.94	1.17
K_2O	4.24	4.30	3.20	2.15	-
H_2O+	3.61	-	-	-	-
H_2O-	0.40	-	-	-	-
P_2O_5	0.07	-	-	-	-
Total	99.74	95.0	100.6	99.7	99.6

C.I.P.W. norms

	1R	1G
Or	25.0	25.6
Ab	26.7	28.3
An	0.0	-
Ne	32.9	28.4
Ac	-	3.2
Ns	-	0.2
Di	8.3	6.9
Ol	0.5	2.2
Mt	1.4	-
Il	0.6	0.3
Ap	0.2	-
H_2O	4.0	-
Total	99.6	95.1
D.I.	84.6	82.3
Ne	56.0	53.1
Ks	16.8	17.7
Qz	27.2	29.2

[1]Total Fe reported as Fe_2O_3. [2]Total Fe reported as FeO.

1R Vitrophyric phonolite from margin of phonolite dyke, Rocky Point, 1.5 km north-north-east of Port Chalmers, East Otago. Grid reference: Dunedin 1:63,360. 164/909802. Analyst G.I.Z. Kalocsai.

1G Residual glass in 1R.

1N Nepheline phenocrysts in 1R ($\Sigma Si+Al+Fe^{3+}$ = 16.06 based on 32 0; $Ne_{80.2}Ks_{11.8}Qz_{8.0}$ wt.%).

1F Anorthoclase phenocrysts in 1R ($Or_{13.2}Ab_{69.9}An_{16.9}$ wt.%).

2 Sodian ferrosalite phenocrysts in 1R (Σxy = 2.02, based on 6 0; $Ca_{47.7}Mg_{18.6}Fe_{33.7}$ atom %).

A Highly Undersaturated Vitrophyric Phonolite from the Dunedin Volcano, New Zealand

The phase petrology of moderately undersaturated phonolitic liquids plotting in the alkali feldspar field in the residua system and the compositional trends of liquid residua generated essentially by low-pressure alkali feldspar fractionation have been evaluated by Carmichael (1964) and Nash *et al.* (1969). There are apparently no data defining fractionation trends and compositions of residua from more highly undersaturated salic melts whose crystallization commenced in the nepheline field in the residua system. Natural melts with this composition are apparently quite rare (*see* Hamilton and MacKenzie, 1965, Fig. 5); the nosean phonolite of Wolf Rock, Cornwall, is one example for which chemical data on the host and its felsic phases are available (Tilley, 1959) but this volcanic is essentially holocrystalline and its fractionation behaviour at low pressures is unknown.

The highly undersaturated vitrophyric phonolite (Table 2, No. 1R) discussed herein was collected from the margin of a phonolite dyke about 0.5 metre wide, intruding alkali basalt (Careys Basalt) at Rocky Point, some 1.5 km north-east of Port Chalmers, near the eroded core of the Dunedin Volcano (*see* Allen, 1974, Fig. 2). The vitrophyric phonolite contains conspicuous phenocrysts of euhedral nepheline (Table 2, No. 1N) and euhedral to subhedral anorthoclase (Table 2, No. 1F), which sometimes displays marginal resorption. Green sodian ferrosalite (Table 2, No. 2), and titanomagnetite (with 51.3 mol. % Fe_2TiO_4) are minor phenocryst phases. The phenocrysts are set in abundant pale green glass containing a minor microlite component which consists largely of pale green, feathery quench clinopyroxene (sometimes localized around opaque oxide granules). Rare microlites of apatite and dark brown(?) aenigmatite are also present. The mode of the analysed specimen (Table 2, No. 1R) is: nepheline 16, anorthoclase 9, clinopyroxene 2, glass (+ microlites) 73, titanomagnetite trace (vol.%). Textural relations between phenocrysts indicate that titanomagnetite and clinopyroxene crystallized initially and that they were followed in the crystallization sequence by relatively abundant nepheline and later by anorthoclase.

The Rocky Point phonolite (Table 2, No. 1R) is distinctly sodic (Na_2O/K_2O = 2.4; $Ne_{56.0}Ks_{16.8}Qz_{27.2}$ wt.%), and highly undersaturated (*ne* = 32.9). In major element chemistry it is very

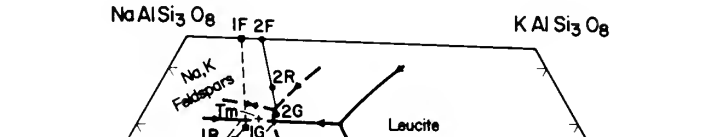

Fig. 4. Vitrophyric phonolite (1R), near Point Chalmers, East Otago, its residual glass (1G), nepheline (1N) and anorthoclase phenocrysts (1F) plotted in the undersaturated quadrilateral in the residua system. Analysis numbers refer to analyses listed in Table 2. Portions of the nepheline-alkali feldspar boundary curves at 1 bar (dashed lines: Schairer, 1957) and at P_{H_2O} = 1 kb (solid lines: Hamilton and MacKenzie, 1965) are shown. The cross T_m = minimum on nepheline-alkali feldspar phase boundary at P_{H_2O} = 1 kb; $Ne_{50}Ks_{19}Qz_{31}$ and 750°C. The ternary reaction point R in the anhydrous system (at approximately $Ne_{46}Ks_{21}Qz_{33}$) falls close to 2G. Analyses 2F, 2G, 2R (solid circles) respectively denote anorthoclase phenocrysts and residual glass in a kenyte from South Victoria Land, Antarctica (Carmichael, 1964, Analyses 1R, 1G, 1F). Compositions X and Y (open circles) are synthetic compositions (Runs 811 and 847, respectively) used to determine 3-phase boundaries at P_{H_2O} = 1 kb (Hamilton and MacKenzie, 1965).

similar to the Dicks Hill phonolite, Otago Peninsula (Price and Coombs, 1975) which is, however, somewhat less undersaturated (*ne* = 25.9) and which also displays a higher Fe_2O_3/FeO ratio, a feature of other phonolites in the Dunedin Volcano (Price and Coombs, 1975; Price and Chappell, 1975).

Discussion

Microprobe analysis of the glass (Table 2, No. 1G; $Ne_{53.1}Ks_{17.7}Qz_{29.2}$) indicates that it is mildly peralkaline, with minor *ac* and a trace of *ns*. Points for microprobe analysis of the glass (using a defocussed beam) were restricted to areas of glass devoid of quench phases and, within the domain of the section, well removed from phenocryst phases. To some extent the appearance of normative *ac* and *ns* has been determined by the somewhat arbitrary (but probably the most rational) procedure of recalculating the Fe_2O_3 and FeO contents of the glass in the same ratio as that of the host. The extent and character of possible changes in the glass chemistry as a result of hydration (particularly as this might affect Na_2O and K_2O) cannot be evaluated but because of compositional consistencies with experimental data (Fig. 4), it is considered that significant changes in the chemistry of the glass probably have not occurred.

In Figure 4, some relevant experimental data for the quadrilateral $NaAlSi_3O_8$-$KAlSi_3O_8$-$NaAlSiO_4$-$KAlSiO_4$ are indicated, for the anhydrous (1 bar) and hydrous systems (P_{H_2O} = 1 kb). At the latter pressure the temperature minimum T_m on the nepheline-alkali feldspar field boundary (T_m = $Ne_{50}Ks_{19}Qz_{31}$; T = 750 ± 7°C) is located close to the ternary reaction point R in the dry system (R is located at approximately $Ne_{46}Ks_{21}Qz_{33}$ at 1020°C) but it indicates the displacement, with increasing P_{H_2O}, of the field boundary in the An-free system towards more undersaturated compositions (*see* Hamilton and MacKenzie, 1965; Morse, 1969). A similar trend exists in analogous systems with increasing An-contents (Norris and MacKenzie, 1976).

The host phonolite, its nepheline and anorthoclase phenocrysts (recalculated An-free), and the residual glass have been plotted in the residua system (Fig. 4). In this projection the host falls in the nepheline field, so that initial precipitation of this phase moved the composition of residual liquids (in projection) towards a natural nepheline-alkali feldspar field boundary located at relatively less undersaturated compositions. Nepheline was then joined by alkali feldspar, in this instance an An-rich anorthoclase. This interpretation of the felsic crystallization sequence is consistent with textural relations between the felsic phenocrysts. It will be noted that the residual liquid approaches but does not reach the experimental field boundaries (Fig. 4). If leaching of alkalis (particularly Na_2O) has occurred, the original obsidian would have contained more *ns* but its position in the residua system would remain essentially unchanged unless it is assumed that Si and Al were also removed from the glass. The similar configuration of the three-phase boundary delineated by the join 1N-1R-1G and experimentally determined three-phase boundaries suggests that alkali leaching, if it occurred, was not selective. If Si and Al have been in fact removed the residual liquid 1G would plot closer to the experimental nepheline-feldspar field boundaries, a trend which is also achieved if conventional CIPW normative procedures are disregarded and all excess Na_2O, reflecting

peralkalinity, is allotted to *ns*, Fe_2O_3 being assigned exclusively to *mt*. The parameters of the glass in the residua system then become $Ne_{52.3}$ $Ks_{17.3}Qz_{30.4}$ and the glass now plots very close, perhaps coincidentally, to the hydrous experimental field boundary determined at P_{H_2O} = 1 kb.

Be this as it may, the crystallization history of the melt may have been polybaric, and hence by analogy with the experimental system the natural field boundary may have varied its position slightly in response to varying P_{H_2O}. This interpretation is consistent with the occurrence of partially resorbed anorthoclases of (?) early crystallization which subsequently were in disequilibrium with liquid as the field boundary shifted towards the Ab-Or join, probably in response to decreased P_{H_2O} following loss of water along dyke contacts. Nepheline continued to crystallize, now accompanied by a somewhat later generation of euhedral anorthoclase. Quenching finally occurred at a temperature of approximately 775°C, suggested by the composition of the nepheline phenocrysts (Hamilton, 1961).

Carmichael (1964) and Nash *et al.* (1969) have demonstrated the peralkaline character of residua (in which Na + K > Al) in vitrophyric phonolites whose felsic crystallization commenced in the alkali feldspar field. Peralkalinity is a consequence of the so-called 'plagioclase effect' (Bowen, 1945). In synthetic mixtures of $NaAlSi_3O_8$ with a Ca-bearing second component (e.g. $CaSiO_3$) the feldspar which initially separates is a Ca-bearing plagioclase. Peralkalinity thus may result from the preferential incorporation of Ca (and Al) into sodic feldspar crystallizing from a melt devoid of a normative $CaAl_2Si_2O_8$ component and rocks with *di* and/or *wo* in their norms have compositions that would permit the 'plagioclase effect' to operate (Table 2, Nos. 1R, 1G, 1F).

The norm of the glass and the sparse development of groundmass aenigmatite indicate the peralkaline character of the residuum in the Rocky Point phonolite but the level of normative peralkalinity, following the precipitation of 25% of highly aluminous felsic phenocrysts from an apparently *an*-free liquid, is actually relatively unimpressive. In contrast the host kenyte 2R (Fig. 4) initially contained 5.8 *an* but its vitric residuum, following the extraction of 20% anorthoclase ($Or_{17}Ab_{63}An_{20}$), was completely purged of *an* and now contains 4.2% *ac* (Carmichael, 1964). The plagioclase effect in the Rocky Point phonolite was partly suppressed by the early separation of abundant sodic nepheline which was relatively more peralkaline (Na + K/Al = 0.89) than the anorthoclase of later crystallization (Na + K/Al = 0.68). Consequently it is unlikely that crystallization of felsic phases from strongly undersaturated salic melts will induce significant peralkalinity in the residua until the latter became essentially Ca-free (and Al-deficient) following the precipitation of relatively abundant Ca-bearing alkali feldspar. In highly undersaturated salic volcanics this phase might ultimately dominate the felsic mineralogy but in this particular phonolite it is still largely occult in the vitric residuum (in part in *di*). Pronounced peralkalinity will thus occur only at relatively evolved stages in the fractionation of highly undersaturated *ac*-free phonolitic liquids in which nepheline is a near-liquidus phase and it must follow somewhat prolonged crystallization on or close to the respective alkali feldspar-nepheline field boundaries. As with olivine nephelinite-phonolite associations, already discussed, it is debatable whether the low-pressure fractionated derivative liquid and crystal extract can be 'cleanly' separated at such an advanced stage of crystallization.

The composition of the residual liquid at this advanced stage is unknown but consideration of the configuration of a three-phase triangle (assuming equilibrium crystallization) whose base (assuming limited nepheline enrichment in Ks) is the join 1N-1R (bulk rock) - (more Or-rich alkali feldspar, indicated by anorthoclase zoning to more Or-rich rims) and whose apex is defined by a more evolved residuum 1G' (on or close to the field boundary) suggests that 1G will move towards minimum melting, increasingly peralkaline compositions 1G' which would be relatively more potassic (in projection) than T_m, the experimentally determined minimum composition in the Ca-free system at P_{H_2O} = 1 kb. This postulated trend agrees with experimental data on the calcium-bearing system $NaAlSiO_4$-$KAlSiO_4$-$CaAl_2Si_2O_8$-SiO_2 at P_{H_2O} = 1 kb where the eutectic composition in the plane containing 3% An is now close to $Ne_{40}Ks_{30}Qz_{30}$ (Norris and MacKenzie, 1976). A corollary of this observation is that some Al may have been lost during hydration of the vitric groundmass in the host which, as a pristine vitrophyric obsidian, may have contained some normative *an* (*cf.* Table 1, No. 1R), developed largely at the expense of *di*.

OPERATIONS AT HIGH PRESSURES

Following Kuno's classic (1964) account of high-pressure megacrysts of aluminous ortho- and clinopyroxene coexisting with Cr-diopside lherzolite xenoliths in an "alkali olivine-basalt or hawaiite" (*hy* = 8.8; normative plagioclase 100 *an*/*ab*+*an* = An_{44}) at Taka-sima, north Kyushu, an increasing number of moderately evolved 'intermediate' alkaline volcanics bearing the stamp of high-pressure (upper mantle) ancestry has been described. Most occurrences are from the Cainozoic volcanic provinces in eastern Australia but overseas localities of high-pressure alkaline volcanics with 'evolved' characteristics are also known (e.g. Hutchison *et al.*, 1975; Chapman, 1976). The volcanics contain Cr-diopside lherzolite xenoliths, which are frequently accompanied by various megacryst species of demonstrable high-pressure origin. The hosts range in composition from hawaiite and nepheline hawaiite (Wilkinson and Binns, 1969; Green and Hibberson, 1970; Green *et al.*, 1974; Irving and Green, 1976; Ellis, 1976) through mugearite and nepheline mugearite (Green *et al.*, 1974; Irving and Green, 1976) to nepheline benmoreite (Price and Green, 1972; Green *et al.*, 1974). It may be commented that the Pigroot (North Otago) "mafic phonolite" (Price and Green, 1972) is difficult to classify according to the nomenclature of Coombs and Wilkinson (1969). Its normative plagioclase is highly sodic (An_3) but it has a D.I. (56.3) which is more characteristic of mugearitic lavas. The most evolved lherzolite-bearing alkaline volcanic so far reported appears to be the phonolite from the Bokkos plug, Nigeria (Wright, 1969; Irving

and Price, 1974). Complete chemical data on this phonolite apparently have yet to be published but it has a relatively high *mg* value (50.9) (MgO = 1.1, FeO_{total} = 1.9) and is rich in alkalis (Na_2O + K_2O = 13.3). In addition to the examples noted above, over fifty Tasmanian occurrences of "fractionated lherzolite-bearing alkaline rocks (with *mg*-numbers < 68)" have been recognized by Sutherland (1974). Some of these will be examined subsequently in slightly more detail (Fig. 6).

The origin of these relatively 'evolved' alkaline volcanics must be sought ultimately at pressures greater than 9-10 kb and hence genetic controls operated in a pressure regime(s) markedly different from that usually envisaged for the generation of liquids with comparable compositions. The latter have been widely interpreted as relatively low-pressure fractional crystallization derivatives of more mafic parents in sub-volcanic 'magma chambers'. However the genesis of former upper mantle residents has also been interpreted in more-or-less similar terms. That is, the preferred model relates the origin of 'high-pressure' hawaiites and more evolved alkaline volcanic liquids to crystal fractionation under hydrous conditions, or, more specifically, to fractionation of 'wet' basanitic (7-8% H_2O) or alkali basaltic parents at upper mantle pressures (15-20 kb) dominated by kaersutitic amphibole, accompanied by minor but variable olivine and clinopyroxene (± biotite) (Irving and Green, 1972; Green *et al.*, 1974; Irving and Green, 1976; Ellis, 1976; *see* Borley *et al.*, 1971; Kesson and Price, 1972; Flower, 1973; Price and Chappell, 1975).

High-Pressure Fractionation

The viability of this model, as it might relate to specific 'evolved' volcanics from various Australian volcanic provinces, will be examined with particular reference to one of the best documented Australian volcanic provinces, namely the Upper Pliocene to Holocene Newer Volcanics (Newer Basalts) of Victoria and South Australia (Irving and Green, 1976). In addition to tholeiites this province contains a spectrum of alkaline volcanics ranging from alkali basalt to hawaiite, and basanite to nepheline mugearite. Many lavas within this compositional spectrum display evidence of their upper mantle ancestry (Irving and Green, 1976). The widespread basanites (the average *M* value for 25 lherzolite-bearing examples = 65.6; Table 3) are mildly potassic (Na_2O/K_2O = 1.86) and are associated - generally at separate eruptive centres - with nepheline hawaiites (average *M* = 63.6; Na_2O/K_2O = 2.11) and nepheline mugearites (average *M* = 63.0; Na_2O/K_2O = 1.96). These *M* values are based to a large extent on the Fe_2O_3/FeO ratios adopted by Irving and Green (1976), namely 0.20 for basanites (0.25 for Mount Leura basanites), 0.20 for nepheline hawaiites, and 0.50 for nepheline mugearites. All examples included in these averages contain Cr-diopside lherzolite xenoliths (*cf.* Frey and Green, 1974) and high-pressure megacrysts also occur at many localities (Irving, 1974b; Wass and Irving, 1976; Ellis, 1976). It seems most unlikely that crustal contamination has played a role in the genesis of the evolved members of the Newer Basalts because the $^{87}Sr/^{86}Sr$ ratios for 14 examples (of all major chemical types) are within the normal range for uncontaminated modern basalts (Irving and Green, 1976).

Compared with their analogues from the type areas or from classical well-documented volcanic series elsewhere, the eastern Australian lherzolite-bearing hawaiitic and mugearitic volcanics collectively display important compositional differences. More specifically, they are generally significantly richer in MgO, for a given D.I., than similar volcanics elsewhere (Fig. 5), reflected in the relatively high *M* values of the Victorian Newer Volcanic averages, already noted. On the basis of normative plagioclase compositions and differentiation indices these lavas are appropriately termed hawaiite, nepheline mugearite, etc. (Coombs and Wilkinson, 1969) but their MgO contents, at least to D.I. ~ 55, approach or may exceed the MgO contents of 'average' alkali olivine basalts (Fig. 5). For example, the average mugearite composition computed by Nockolds (1954) has a low *M* value (*M* = 39.3) and the type mugearite from Skye (Muir and Tilley, 1961) has *M* = 35.6, reflected in the relatively Fe-rich olivines and clinopyroxenes in mugearites from other classic localities (Muir and Tilley, 1961). In contrast, olivine phenocrysts in the nepheline mugearite from Mt Anakie (East) are relatively Mg-rich (Fo_{73}; Ellis, 1976). The relatively high *M* values of the lherzolite-bearing volcanics in Figure 5 are at the same time accompanied by relatively high Na_2O + K_2O, oxides which largely determine the differentiation indices. There is also a tendency for these particular lherzolite-bearing volcanics to be relatively sodic. In order to emphasize the evolved character of the lherzolite-bearing lavas plotted in Figure 5, selection was restricted to examples (with the sole exception of the Auckland Island hawaiite; Green and Hibberson, 1970) with normative plagioclase compositions less calcic than An_{40}. Although relatively rich in MgO, the volcanics under discussion display no obvious divergence from the 'generalised' trend illustrating variation in total Fe (expressed as FeO + Fe_2O_3), the lherzolite-bearing types of intermediate D.I. plotting in a more-or-less random fashion with respect to the trend defined by average compositions of well-documented and type rocks (Fig. 5).

The compositions of the average nepheline basanite, nepheline hawaiite, and nepheline mugearite from the Newer Volcanics listed in Table 3 indicate the constraints, discussed below, on the character of crystal extracts composed of kaersutite, olivine and clinopyroxene. The most significant compositional parameters defining this moderately undersaturated lineage are *M*, normative plagioclase composition, and D.I. With increasing degree of 'evolution', *M* decreases only slightly, normative plagioclase becomes decidedly more sodic, total alkalis increase (Na_2O + K_2O increases from 6.0 to 8.0%) and the respective D.I.'s increase from 35.9 to 52.0 (Table 3). If anything, normative nepheline decreases slightly, in contrast to similar lineages in some provinces which have been interpreted as the products of low-pressure fractionation of more mafic parents.

The genesis of the more undersaturated 'evolved' members of the Newer Volcanics via high-pressure fractionation of basanitic parents will

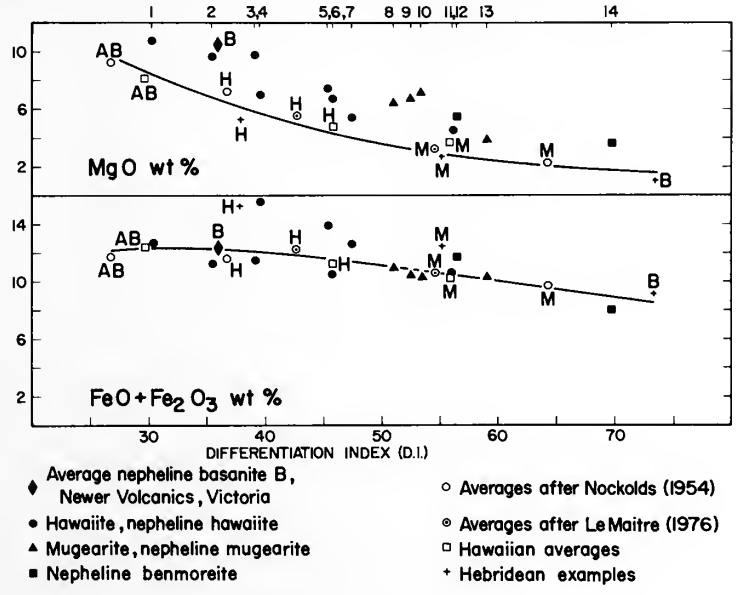

Fig. 5. Variation of MgO and FeO + Fe_2O_3, with differentiation index D.I., of evolved alkaline volcanics containing Cr-diopside lherzolite xenoliths. The generalised curves indicate variation in MgO and FeO + Fe_2O_3 in ('average') alkali basalt (AB), hawaiite (H), mugearite (M), and benmoreite (B). Hawaiian averages (open squares) are based on the data of Macdonald and Katsura (1964) and the Hebridean examples (crosses) refer to the analyses cited by Muir and Tilley (1961) and Tilley and Muir (1964). 1, hawaiite, Auckland Island (Green and Hibberson, 1970). 2, hawaiite, Mt Kurweeton, Victoria (Irving and Green, 1976). 3, nepheline hawaiite (average of 2), Mt Elephant, Victoria (Irving and Green, 1976). 4 and 5, nepheline hawaiites, Runnymede and Flinty March, Tasmania (Green *et al.*, 1974). 6, hawaiite, near Kyogle, New South Wales (Wilkinson and Binns, 1969). 7, hawaiite, Kingston, Tasmania (Green *et al.*, 1974). 8 and 9, nepheline mugearites from Mt Franklin (average of 2) and The Anakies (East) (average of 3), Victoria (Irving and Green, 1976). 10, nepheline mugearite (2102), The Anakies (East), Victoria (Irving and Green, 1972, 1976). 11, hawaiite, Redcliffe plateau, central Queensland (Green *et al.*, 1974). 12, 'mafic phonolite', northeast Otago (Price and Green, 1972). 13 and 14, nepheline mugearite, Mt Leslie, central Queensland, and nepheline benmoreite, Mt Mitchell, southeast Queensland (Green *et al.*, 1974). With the exception of the Auckland Island hawaiite (No. 1), all xenolith-bearing volcanics have 100 $an/ab+an < 40$. The nomenclature of the volcanics plotted in Figs. 5 and 6 follows that adopted by the various authors.

be examined semi-quantitatively as a function of the extraction of kaersutite alone, or kaersutite plus lesser olivine and clinopyroxene. The composition of the kaersutite extract (with total Fe expressed as FeO) has been based on the average composition of two kaersutite megacrysts (2110A and B8; Irving, 1974b) from the nepheline mugearite of The Anakies (East) (reflecting the most abundant compositional generation at this locality). The clinopyroxene composition is based on the average of two megacrysts from the nepheline mugearite at Mt Franklin (Irving, 1974b), and that of the olivine megacrysts (apparently unrecorded as yet in the Newer Volcanics) has been taken as $mg = 86$ (i.e. olivine of this composition has been assumed to be in equilibrium with liquids with $M \sim 64$). Because there is only very limited variation in the M values of members of the spectrum nepheline basanite → nepheline mugearite, it has been assumed that there should be relatively little change in the mg values of ferromagnesian megacrysts precipitated from melts within this compositional range (it must be noted, however, that amphibole megacryst mg values do in fact vary sympathetically with host compositions; Ellis, 1976). It is also recognized that successive crops of high-pressure phases will precipitate from liquids of changing composition and hence removal of crystal fractions with constant compositions (although a widely adopted practise in the literature) may not provide accurate indications of residua compositions.

It is also assumed, despite the reservations of some workers (isotopic data are by no means conclusive on a possible accidental origin for high-pressure megacrysts in alkaline volcanics; *see* Stuckless and Irving, 1976), that ferro-

TABLE 3
COMPOSITIONS OF MODERATELY UNDERSATURATED REPRESENTATIVES OF THE VICTORIAN NEWER VOLCANICS AND HYPOTHETICAL HIGH-PRESSURE DERIVATIVES

Analysis number	1	2	3	4	5	6	7
SiO_2	45.7	47.6	49.4	46.2	46.9	49.0	50.3
TiO_2	2.8	2.4	2.2	2.8	2.8	2.3	2.2
Al_2O_3	12.9	13.5	15.6	13.3	13.7	14.5	15.2
Fe_2O_3	2.0	1.9	3.5	1.9	1.8	3.4	3.1
FeO	10.1	9.5	7.0	9.6	9.2	6.8	6.2
MnO	0.2	0.2	0.2	0.2	0.2	0.2	0.2
MgO	10.8	9.3	6.7	10.0	9.0	7.2	5.6
CaO	8.6	8.9	6.7	8.6	8.5	8.9	8.9
Na_2O	3.9	4.0	5.3	4.1	4.4	4.5	4.9
K_2O	2.1	1.9	2.7	2.3	2.4	2.2	2.3
P_2O_5	0.9	0.8	0.7	1.0	1.1	1.0	1.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Fe_2O_3/FeO	0.20	0.20	0.50	0.20	0.20	0.50	0.50
100 $Mg/Mg+Fe^{2+}$ (M)	65.6	63.6	63.0	65.0	63.6	65.4	61.7
Na_2O/K_2O	1.86	2.11	1.96	1.78	1.83	2.05	2.13
			C.I.P.W. norms				
Or	12.2	11.1	16.1	13.3	14.5	12.8	13.3
Ab	12.6	19.4	25.7	14.7	16.1	25.1	29.3
An	11.4	13.1	10.8	11.1	10.3	12.8	12.8
Ne	11.1	8.0	10.2	10.8	11.4	7.1	6.5
Di	21.3	20.7	14.3	20.2	19.8	20.1	19.2
Ol	21.1	18.5	11.9	19.4	17.5	10.4	7.4
Mt	3.0	2.8	5.1	2.8	2.6	4.9	4.4
Il	5.3	4.6	4.1	5.3	5.3	4.4	4.3
Ap	2.0	2.0	1.7	2.4	2.7	2.4	2.7
Total	100.0	100.2	99.9	100.0	100.2	100.0	99.9
100 *an/ab+an*	47.5	40.3	29.6	43.0	39.0	33.8	30.4
D.I.	35.9	38.5	52.0	38.8	42.0	45.0	49.1

1 Average nepheline basanite, Newer Volcanics (25 analyses).

2 Average nepheline hawaiite (7 analyses).

3 Average nepheline mugearite (6 analyses).

4 Derivative after extraction of 5% kaersutite, 2.5% olivine and 2.5% clinopyroxene (see text) from the average nepheline basanite (No. 1).

5 Derivative after extraction of 10% kaersutite, 5% olivine and 5% clinopyroxene from the average nepheline basanite (No. 1).

6 Derivative after extraction of 10% kaersutite, 5% olivine and 5% clinopyroxene from the average nepheline hawaiite (No. 2).

7 Derivative after extraction of 15% kaersutite, 7.5% olivine and 7.5% clinopyroxene from the average nepheline hawaiite (No. 2).

Analyses 1-3 are based on analyses listed by Irving and Green (1976).

magnesian megacrysts are generally cognate with their hosts. For many megacryst occurrences this interpretation is consistent with appropriate high-pressure experimental data. Rejection of a strictly cognate origin of megacrysts virtually eliminates any opportunity to evaluate potential high-pressure fractionation trends quantitatively. So far as can be ascertained, there is no evidence of hybridism in megacryst-bearing volcanics, i.e. petrological evidence which would support an *accidental* relationship between megacryst and a particular host. On this premise the compositions of high-pressure nepheline hawaiites and nepheline mugearites *plus* their respective megacryst populations ideally should approximate the compositions of their less evolved, essentially unfractionated parents, depending, of course, on megacryst abundances at specific localities. In evaluating compositional controls on derivative liquids following the extraction of high-pressure megacrysts, the proportions of the latter have been applied in only a generalised way. It is possible to provide an 'ideal' solution for a particular melt-derivative liquid combination but an approach of this type permits only restricted application to the much wider problem of high-pressure fractionation controls.

A crystal extract composed solely of kaersutite is inappropriate because its removal results in *increases* in the *M* values of the derivatives, a result of kaersutite MgO (7% MgO, on an anhydrous basis) being less than MgO of the parent basanite. Olivine extraction is a highly efficient mechanism to decrease *M* values and hence for this particular lineage, in which *M* values remain more or less constant, olivine cannot be a major phase in the crystal extract. Crystallization of excessive high-pressure jadeitic K-free clinopyroxene would yield derivatives with *decreased* Na_2O/K_2O ratios - a trend which is opposite to that displayed by the natural assemblages (Table 3).

An extract composed of kaersutite, olivine and clinopyroxene in the somewhat arbitrary ratio of 2:1:1 has been selected to test the fractionation model semi-quantitatively. Removal of 10% of this extract from the average nepheline basanite (Table 3, No. 1) yields a derivative similar to the average nepheline hawaiite (Nos. 2 and 4) as indeed does the removal of 20% of this extract (Table 3, No. 5), which also results in a somewhat excessive increase in alkalis. Extraction of 20% and 30%, respectively, of the kaersutite-olivine-clinopyroxene fraction from the average nepheline hawaiite - presumably the next stage in the high-pressure operation - yields derivative *M* values, D.I.'s and normative plagioclase compositions that are essentially compatible with the average nepheline mugearite (Table 3, Nos. 3, 6, 7) but it does not produce an adequate decrease in CaO, and $Na_2O + K_2O$ have not increased sufficiently to match the alkali contents of the natural nepheline mugearites. Furthermore, the derivatives now show a decided *decrease* in their *ne* contents, a result of the removal of significant amounts of a highly undersaturated phase, namely kaersutite (normatively akin to olivine nephelinite).

Of more relevance, however, is the magnitude of the crystal extract (some 30-40 wt.%) required to pass from nepheline basanite to nepheline mugearite - a natural extract that must have retained a more-or-less constant proportion of phases to account for the geochemical coherence, in terms of major and minor element chemistry, of nepheline mugearites at different eruptive centres. It now becomes appropriate to examine the nature of the megacryst assemblage at those centres in the Newer Volcanics where the lineage nepheline basanite → nepheline mugearite is developed.

High-pressure fractionation as the major genetic control, applied to the more 'evolved' undersaturated representatives of the Newer Volcanics, and indeed to similar volcanics elsewhere, becomes even more questionable when the general character of the megacryst assemblage at the Newer Volcanic localities and other eastern Australian alkaline provinces is examined. Of seventeen localities of Newer Volcanics where the representatives of the nepheline basanite, nepheline hawaiite, nepheline mugearite lineage occur, megacrysts have been recorded only at eleven localities. At these, black vitreous clinopyroxene is either the most abundant ferromagnesian megacryst (anorthoclase may be the most abundant megacryst species at some localities) or is the sole megacryst species at eight localities, kaersutite being essentially absent (Irving, 1974b; Wass and Irving, 1976). Kaersutite is very abundant at only one locality, namely The Anakies (East) and it has been recorded as a 'very rare' megacryst at Mt Noorat. It may be noted that Ellis (1976, Table 2) records the abundance of amphibole megacrysts at The Anakies (East) as 'scarce'. Kaersutite is also a rare species in the nepheline hawaiite at Lake Keilumbete (Ellis, 1976). Olivine megacrysts apparently have yet to be recognised in the Newer Volcanics but olivine was clearly a high-pressure phase at some centres (e.g. Mt Leura, Mt Noorat and Mt Shadwell), indicated by the occurrence at these centres of cognate wehrlite inclusions belonging to the Ti-augite series. However at these particular centres Ti-augite inclusions are subordinate to Cr-diopside lherzolite xenoliths by a factor of twenty or more (Irving, 1974a).

The Tasmanian lherzolite-bearing hawaiites, mugearites and benmoreites (and their more undersaturated equivalents) are also relatively rich in MgO relative to D.I. (Sutherland *in* Leaman, 1976; Sutherland, *unpublished data*), with a tendency for MgO to decrease somewhat more regularly with increasing D.I. than the Victorian and other examples (Figs. 5 and 6); $FeO + Fe_2O_3$ tends to remain more or less constant with increasing D.I. Unfortunately many analyses (Leaman, 1976, Table 2) display atypically high Fe_2O_3/FeO ratios but ten analyses (unpublished) have *M* values between 74 and 56 (*M* = 68-49 when the analyses are corrected on a basis of $Fe_2O_3/FeO = 0.15$). The XENMEG catalogue (Wass and Irving, 1976) lists only one Tasmanian megacryst locality with kaersutite (abundance not stated), namely the nepheline hawaiite at Flinty Marsh (Green *et al.*, 1974). Indeed, megacrysts appear to be comparatively rare in Tasmanian Cainozoic alkaline volcanics. Three Queensland localities of lherzolite-bearing 'evolved' alkaline volcanics have been listed by Green *et al.* (1974). Kaersutite is abundant only in the Mt Mitchell nepheline benmoreite and 'sparse' kaersutite has been recorded in the Mt

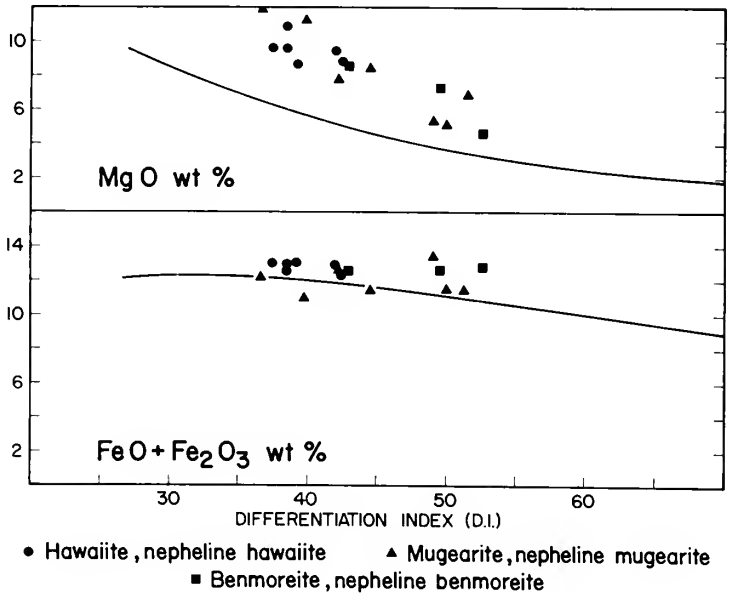

Fig. 6. Variation, with respect to differentiation index D.I., of MgO and $FeO+Fe_2O_3$ of evolved Tasmanian alkaline volcanics containing Cr-diopside lherzolite xenoliths (Sutherland, *unpublished data*). Normative plagioclase compositions in all cases are less than 40. Generalised curves are those depicted in Fig. 5.

Leslie nepheline mugearite where it is there subordinate to anorthoclase.

The patchy and variable distribution and the aberrant proportions of megacryst species (in which zoning is by no means conspicuous) at these centres thus do not favour a model based largely on kaersutite fractionation. At more than fifty localities of lherzolite-bearing 'evolved' alkaline volcanics in eastern Australia, kaersutite megacrysts are only sufficiently abundant at three (The Anakies (East), Mt Mitchell, and Spring Mount (Wilkinson, 1962; Binns *et al.*, 1969)) to suggest that amphibole fractionation might have exerted significant compositional controls in any derivatives. It could be argued that the aberrant character of megacryst populations *at the outcrop* does not detract from the fractionation model because of pre-eruptive removal of (certain) megacrysts, either as a result of gravity or perhaps some form of flow differentiation. These would not explain the preferential removal of kaersutite ($\rho \sim 3.2$) relative to the more widespread and relatively more abundant megacrysts of clinopyroxene ($\rho \sim 3.4$). Furthermore, kaersutitic amphibole is generally rare in Ti-augite wehrlite inclusions in the Newer Volcanics (Irving, 1974a) where it occurs largely as an intercumulus phase (Ellis, 1976). Finally, it must be noted that the relative frequency of occurrences of megacrysts in the Newer Volcanics (clinopyroxene > feldspars > kaersutitic amphibole > (olivine)) is the same as in the (dominantly) Cainozoic alkaline volcanic rocks of eastern Australia (Wass and Irving, 1976). Clinopyroxene is present at approximately 40% of megacryst localities in eastern Australia but kaersutitic amphibole occurs at only 11% of localities.

Binns *et al.* (1969) provisionally concluded that high-pressure fractionation offers the possibility of only limited variation in derivative liquid compositions. So far as I am aware, very few data have appeared subsequently to materially change this conclusion and indeed it has been essentially confirmed by evaluation of potential high-pressure fractionation trends induced by megacryst precipitation at two north-eastern New South Wales localities (Lawlers Creek and Boomi Creek; Wilkinson, 1975a, 1975b). For example, removal of 20% olivine and 20% clinopyroxene from a hypothetical olivine nephelinite parent to yield the host olivine nephelinite at Lawlers Creek results in a moderate decrease in M values but the composition of the derivative is otherwise essentially unchanged (Wilkinson, 1975a). In view of the problems associated with the production of nepheline mugearite from basanite the possibility of deriving even more felsic (phonolitic and trachytic) liquids from parental mafic melts via high-pressure (amphibole) fractionation becomes even more remote. Whether such felsic liquids can be generated by partial melting in the upper mantle, as suggested by Wright (1971), is still uncertain and requires experimental examination. This proposal does, however, receive support from the isotopic data on certain northeastern Nigerian trachytes and phonolites (Grant *et al.*, 1972).

The formation of cognate ultramafic cumulates belonging to the Ti-augite inclusion group indicates gravitative movement and accumulation of ferromagnesian phases at elevated pressures (*cf.* Kushiro *et al.*, 1976) but once megacryst precipitation during a period of magma stagnation has taken place at upper mantle pressures, preservation of megacrysts in their alkaline hosts (especially where megacrysts co-exist with Cr-diopside lherzolite xenoliths) indicates very rapid ascent of liquid + megacrysts (+ xenoliths) to low-pressure eruptive regimes (*cf.* Kushiro *et al.*, 1976; Biggar and Clarke, 1976). It is thus a reasonable assumption that many megacryst populations (as now observed at the outcrop) are representative of the extent of high-pressure crystallization and the character of the high-pressure precipitate.

One of the very few well-documented examples of fractionation at elevated pressures in which there is close correlation between field and experimental data has been provided by Knutson and Green (1975) who have demonstrated the potential production of mugearite from near-saturated hawaiite at deep crustal pressures (6.5-8 kb), following extraction of olivine, clinopyroxene, orthopyroxene, plagioclase and minor ilmenite and apatite (collectively equivalent to approximately 27% crystallization of the hawaiite parent). It should be noted, however, that plagioclase (generally absent from upper mantle megacryst populations) comprises 56% of the megacryst-cumulate assemblage, that Cr-diopside lherzolites are absent from the mildly undersaturated alkaline volcanics in this particular province, and that the parent hawaiite (M = 45.9) is itself interpreted as a fractionated derivative from transitional olivine basalt (with M = 65-75).

A further example may be cited. The Al-spinel ultramafic-mafic inclusion suite at Boomi Creek, northwest of Barraba in northeastern New South Wales (Wilkinson, 1975b), has been interpreted in the light of textural, mineralogical and chemical data as the remnants of a layered ultramafic-mafic 'pluton' which initially crystallized at pressures in the vicinity of 10 kb and subsequently re-equilibrated at subsolidus temperatures (*ca* 950°C) and comparable pressures. Fractionation at moderate pressures of parental K-poor subalkaline magma, controlled largely by extraction of olivine and subcalcic clinopyroxene, decreased the saturation levels of derivative liquids. This interpretation favouring moderate pressure fractionation is internally consistent with available experimental data but what is more important, it finds support in the major development of ultramafic cumulates, a prime component to the fractionation model.

An Alternative High-Pressure Model

Ferromagnesian fractionation has been invoked as the major control in the genesis of high-pressure mugearites, hawaiites, etc., mainly because their M values have been considered too low for these liquids to have been initially in equilibrium with parent peridotite with $mg \sim 90$ - or, more specifically, pyrolite with M = 89.2. It has been proposed that lherzolite-bearing alkaline basalts with $M \sim 70$ represent unfractionated upper mantle liquids whose rapid movement to the surface inhibited ferromagnesian fractionation en route. In contradistinction, somewhat similar lherzolite-bearing alkaline volcanics (with M = 60-68) have been interpreted as 'second order' derivatives - the end-products of later, superimposed high-pressure fractionation controlled (largely) by ferromagnesian phases. This proposal derives in part from the assumption that *only* basaltic liquids can be generated by partial melting in the upper mantle, an assumption that is, of course, implicit in the definition of pyrolite - "the composition of pyrolite is *defined* by the property that it is required to produce a basaltic magma upon partial melting, leaving behind a residual refractory peridotite" (Ringwood, 1975, p. 180). An additional implication in the proposal that liquids with M = 70±2 must have been in equilibrium with source peridotite containing olivines with mg = 88-90 (Green *et al.*, 1974) is the assumption that the upper mantle is essentially homogeneous in its M value. This is also open to question. Upper mantle peridotite heterogeneity is well illustrated by the data of Hutchison *et al.* (1975) which clearly indicate the variation between suites of Cr-diopside lherzolites and associated ultramafic inclusions from 5 localities in the Massif Central, France. It is also indicated by the relatively Fe-rich character of several Cr-diopside lherzolite xenoliths briefly reported below.

If the major elements of Cr-diopside lherzolite xenoliths are residual, following extraction of a basaltic component (up to 20% partial melting) (Frey and Green, 1974; Ringwood, 1975, pp. 177-178; Irving, 1976) it is more-or-less axiomatic that the mg values of 'undepleted' source peridotites were less than those of their respective residua. Differences in the mg values of parents and residua will vary according to the degree of partial melting envisaged in the source peridotite. It is difficult to generalise on the composition of upper mantle peridotite xenoliths but the available data give the impression that the most commonly analysed representatives of the Cr-diopside lherzolite xenolith group have mg = 90±2. If these xenoliths are residua, the mg values of many undepleted peridotites must have been significantly less than 90, in accordance with experimental data indicating increases in mg values (at a given pressure) of residual phases in peridotite as a function of temperature increase (~ degree of partial melting). Thus olivine mg in residual garnet peridotite increases by about 2.5% with 15-20% partial melting at 20 kb (Mysen and Kushiro, 1976) and by a similar amount over a temperature increase of 80-100°C (a comparable temperature increase induces 15-20% partial melting of garnet peridotite; Mysen and Kushiro, 1976) for water-saturated pyrolite (less 40% olivine) at 20 kb (Green, 1976) (*see* references in Wilkinson, 1976, p. 196).

If K_D (the olivine-liquid Fe-Mg distribution coefficient) is indeed a function of fo_2, T, P and the composition of the source material (Mysen, 1975) it becomes increasingly difficult to adopt K_D (and olivine-liquid Fe-Mg partition relationships) as a critical parameter in the recognition of unfractionated primary upper mantle liquids. If these complexities are disregarded for the time

being (*cf.* Green, 1976), an alternative but feasible interpretation can be applied to the histograms (analysis frequency vs. basalt *M* value) for 130 lherzolite-bearing volcanics from eastern Australia (Green *et al.*, 1974, Fig. 1). On adjusted (lower) Fe_2O_3/FeO ratios (0.15-0.20) - a reasonable procedure because of the susceptibility of alkaline volcanics to alteration - approximately 70% of the specimens (*M* = 60-68) can be interpreted (if ferromagnesian fractionation is disregarded) as partial melts initially in equilibrium with olivine with *mg* = 83-88. Depending on the degree of partial melting, the latter would be more Mg-rich than olivines in the undepleted source peridotites.

This interpretation assumes *minimal* high-pressure ferromagnesian fractionation of the partial melts in question. Since olivine is the most efficient phase in decreasing the *M* values of derivative liquids (olivine should occur on or near the liquidi of alkali basaltic melts at pressures up to 12-15 kb and at higher pressures for *ol*-rich basanitic liquids) evidence in favour of high-pressure olivine fractionation should be provided by widespread and, at many localities, relatively abundant olivine megacrysts. In fact, olivine is a relatively rare megacryst species in eastern Australian alkaline volcanic provinces (Wass and Irving, 1976) and, so far as can be ascertained, in provinces elsewhere. Orthopyroxene is also an efficient megacryst phase in decreasing *M* values of derivative liquids but like olivine it is also a comparatively rare megacryst species (*see* Wilkinson and Binns, 1969). The high frequency of occurrence of clinopyroxene megacrysts suggests that many alkaline liquids crystallized under conditions where clinopyroxene was the major liquidus or near-liquidus phase at elevated pressures but relatively extensive precipitation of clinopyroxene is necessary to induce any significant changes in the *M* values of any derivatives. Extraction of jadeitic clinopyroxene also inhibits enrichment in Na in derivative liquids. It is concluded that high-pressure ferromagnesian fractionation was generally minimal for these particular xenolith-bearing lavas because magmas which transported Cr-diopside lherzolite xenoliths rapidly to the surface were unlikely to have left olivine or pyroxene megacrysts behind.

It is important to emphasize that olivine compositions in the range *mg* = 83-88 represent olivine compositions *coexisting with melt*. In view of the compositional variation of phases in residual peridotites as a function of the degree of partial melting (Mysen and Kushiro, 1976) these *mg* values must therefore be *higher* than those in the undepleted source peridotite - often by some 2-3% at least. Hence the *mg* values of many 'parental' olivines were thus most likely in the range *mg* = 81-86 before the onset of partial melting.

The problem of generating liquids with *M* values less than 68 by partial melting of highly magnesian upper mantle source peridotites diminishes to a large extent if it is assumed that the primitive upper mantle in at least some regions of magma generation is relatively Fe-rich, compared with the compositions of the upper mantle source peridotites most commonly envisaged (*mg* ~ 90). This proposal has been discussed by Wilkinson and Binns (1978), with particular reference to the genesis of the extraordinarily voluminous continental flood 'basalts' (often more appropriately termed tholeiitic andesites), but also tested with least squares calculations assuming a relatively Fe-rich source peridotite (*mg* = 83.7) and a derivative corresponding to the average hawaiite (*mg* = 53.1; Nockolds, 1954). The proposal is highly relevant to genetic considerations of the hawaiites and mugearites under discussion. Its validity obviously depends to a large extent on the documentation of xenoliths of the Cr-diopside lherzolite group with *M* (or *mg*) values significantly less than 88.

Some data on a number of these inclusions are now available. The most Fe-rich example is a Cr-diopside lherzolite xenolith from an analcimite at Spring Mount, New South Wales (*mg* = 79; Wilkinson and Binns, 1978). The most commonly described type - admittedly apparently rare compared with relatively more Mg-rich lherzolites - appear to have *mg* values between 85 and 87. These include two other lherzolite xenoliths (*mg* ~ 85) from northeastern New South Wales localities (Wilkinson, 1975a, 1975b), five examples from Hawaiian alkaline hosts (*mg* = 85-87; White, 1966; Kuno and Aoki, 1970; Kushiro, 1973), one from Ogusoyama, southwestern Japan (*mg* = 86; Ishibashi, 1970), and one from Tarreyres, Massif Central, France (*mg* = 86; Hutchison *et al.*, 1975).

The *mg* values are based either on xenolith analyses or, more commonly, on analyses of their constituent olivines and pyroxenes - xenolith *mg* values are reasonably well defined by the *mg* values of their respective olivines and orthopyroxenes. For a given xenolith *mg* < *M* but when MgO is very high and pristine Fe_2O_3 of the xenolith is low (*cf.* Frey and Green, 1974) *mg* closely approximates to *M*. In the absence of other data specifically defining the affinities of a particular peridotite inclusion, phases from Cr-diopside xenoliths (and hence the affinities of the xenolith) generally may be discriminated from phases in Ti-augite ultramafic inclusions by the relatively higher Cr_2O_3 and lower TiO_2 contents of the clinopyroxenes in Cr-diopside lherzolites (Wilkinson and Binns, 1978).

Hutchison *et al.* (1975) interpreted the Fe-rich character of the Tarreyres xenolith (T33) as probably the result of "magmatic enrichment in Fe, Ti and other fusible oxides". This interpretation derives largely from the rather restrictive premise that undepleted upper mantle should yield only partial melts no more evolved than basalt. The chemistry of xenolith T33 can be equally well interpreted as a true reflection of its relatively undepleted character - Al_2O_3 and CaO are 4.00 and 4.38% respectively, and it may therefore be a potential parent to partial melts with *M* values of 60-63.

There are apparently few, if any, published trace and minor element data of hawaiitic and mugearitic eruptives of high-pressure origin and of relatively Fe-rich Cr-diopside lherzolites (*mg* = 80-87), thereby permitting more detailed chemical evaluations of 'mother-daughter' relationships.

If, however, it is assumed that the most Mg-rich olivine phenocrysts in relatively 'evolved' alkaline extrusives reflect the compositions of residual peridotitic olivines with which the partial melts were initially in equilibrium (*cf.* Green, 1976) it is possible to at least test the feasibility of their direct relation to comparatively Fe-rich lherzolites, assuming minimal high-pressure ferromagnesian fractionation. For example, the nepheline benmoreite from Mt Mitchell in southeast Queensland (M = 53.1, D.I. = 69.7), selected by Green *et al.* (1974) as an example of a fractionated upper mantle liquid derived from basanite largely as the result of kaersutite extraction, contains olivine phenocrysts as Mg-rich as Fo_{83} and hence it could have been a partial melt initially in equilibrium with olivine with mg = 81-83. Olivine phenocrysts in alkaline volcanics from the eastern Azores (Boone and Fernandez, 1971) have compositions largely in the range Fo_{87}-Fo_{80} and there are other examples of 'basaltic' phenocrystal olivines in the Fo_{80}-Fo_{86} range (*see* Brown, 1967, Table lI1; Brown and Carmichael, 1969; Green and Hibberson, 1970). Olivine phenocrysts in Newer Volcanics nepheline basanites and nepheline hawaiites are as Mg-rich as Fo_{86}-Fo_{83} (Ellis, 1976). High-pressure olivine megacrysts and olivines in cognate Ti-augite ultramafic inclusions are rarely more Mg-rich than mg = 88-86 and the most Mg-rich varieties in individual inclusion suites commonly extend to relatively more iron-rich compositions (Wilkinson, 1975a). If it is again assumed that ferromagnesian fractionation of the parent melts, prior to olivine megacryst precipitation, was minimal, the most Mg-rich liquidus olivine compositions suggest that the host liquids were initially in equilibrium with residual peridotite with mg (maximum) = 88-86 (*cf.* Carter, 1970). Detailed analytical data on olivine phenocrysts from a spectrum of evolved alkaline volcanics of suspected high-pressure origin are obviously required, due consideration being given to discriminating cognate phenocrysts from xenocrystal olivines. Accidental xenocrysts of olivine (and tschermakitic orthopyroxene) with mg = 80-87 would of course provide an indirect indication of the relatively Fe-rich character of upper mantle peridotites.

The partial melting of relatively Fe-rich lherzolites, as primitive components of the upper mantle, is suggested as an alternative to a model based on ferromagnesian fractionation in the generation of 'evolved' alkaline volcanics, at least to examples with M values between 55 and 65. It does not, however, clarify the problem of significant alkali enrichment in the partial melts, reflected in relatively sodic normative plagioclase compositions and intermediate differentiation index values. Enrichment in Na may reflect major compositional controls exerted by early entry of jadeitic clinopyroxene into the liquid (the clinopyroxene in the Spring Mount lherzolite xenolith (mg = 79) contains 2.77 Na_2O; Wilkinson and Binns, 1978). There is, of course, also the possibility that the source peridotites originally contained some sodic calciferous amphibole (*cf.* Hariya and Terada, 1973) and/or phlogopite, phases which would preferentially enter derivative melts on relatively small degrees of partial melting of the source lherzolites.

At present there are some obvious constraints to a partial melting model based on relatively Fe-rich source peridotites. For example, there are at present only comparatively limited chemical and mineralogical data on 'undepleted', relatively Fe-rich lherzolite xenoliths (M = 80-86) and hence there is an obvious need to investigate xenolith populations in alkaline hosts at the sampling level adopted by Hutchison *et al.* (1975). Furthermore, only one Fe-rich lherzolite (mg = 85.3) has been subjected to high-pressure experimental studies (Kushiro, 1972). The partial melt (represented by clear, pale green glass essentially devoid of quench crystals) produced in this xenolith at 20 kb, 1460°C anhydrous has a basanitic aspect (ne = 10.0) but the liquid is Al-rich, and consequently its analysis yields a highly calcic normative plagioclase. The M-value (based on Fe_2O_3/FeO = 0.20) is 67; when Fe_2O_3/FeO = 0.15, M equals 66.

The origin(s) of natural igneous assemblages may be constrained by experimental data but the most plausible genetic models are those in which the most fundamental characters of the natural assemblages (field, mineralogical and chemical) *and* relevant experimental data collectively provide a reasonable level of internal consistency. A comparatively simple single-stage partial melting model based on relatively Fe-rich source peridotites for the genesis of hawaiite, nepheline mugearite, etc. - when these lavas are of demonstrable upper mantle origin - is offered as an alternative to a more complex multistage model requiring the initial generation of alkali basaltic or basanitic magmas, (or in some models, picritic), followed by what appear to be unduly excessive high-pressure crystal extracts which in general are not represented in requisite amounts at the outcrop or in the proportions required by models based on experimental data.

CONCLUDING REMARKS

Similar comments are also relevant in genetic interpretations of the alkaline volcanic spectrum in many continental and oceanic eruptive centres. We are here concerned with the genesis of alkaline eruptives with differentiation indices between 50 and 65 and not only with the trachyte-phonolite problem already highlighted by Chayes (1963). Although admittedly a difficult - in many instances, probably quite impracticable - procedure limited by poor outcrop and other constraints, very few studies detail or attempt to detail the relative volumes of the various eruptives and so relate these to a fractional crystallization model. This type of information has been provided for Saint Helena (Baker, 1968), although it may be commented that the "basalt" (M = 50.5, normative plagioclase An_{49}, D.I. = 35.7) selected as parent to a continuously variable volcanic series is closer in composition to hawaiite than to basalt.

Of more concern, however, is the paucity of data on the complementary cumulates (either cognate inclusions or concentrations of single (zoned) crystals) required by the fractional crystallization model, particularly the relatively mafic assemblages necessary in the production of derivatives with intermediate differentiation indices. Borley (1974) has summarised the wide variety of inclusions in oceanic alkaline rocks. Although

inclusions may be abundant at some centres, such as Rodriguez Island (Upton *et al.*, 1967), they have apparently yet to be subjected to detailed and systematic phase mineralogical studies and evaluated as potential by-products of fractionation controls. Clearly, models based on fractional crystallization would assume much higher levels of internal consistency and conviction if inclusion abundances and compositions were evaluated in this way. Are the cognate extracts actually present but ignored? If they are in fact absent this in itself demands some explanation if fractionation is adopted as the prime genetic control. In rebuttal, it could be argued that, because cumulates are rare or absent, they have remained unsampled at depth in the volcanic pile. This may well be so but it is also not unreasonable to assume that at some time(s) during the history of major volcanic centres, earlier cumulates should be sampled and brought to the surface by a rejuvenative phase(s) of volcanic activity.

As an example, a detailed geochemical evaluation of the mildly potassic Gough Island volcanic sequence led Zielinski and Frey (1970) to conclude that fractional crystallization of a basaltic parent involving the removal of olivine, pyroxene, feldspar and olivine was the prime petrogenetic control. Yet "all but one of the rocks considered were fine-grained with only a few phenocrysts" and "a criticism of the fractional crystallization model is that no cumulative rocks were obtained by Le Maitre except for the picrite basalt" (Zielenski and Frey, 1970, p. 246, p. 253). According to Le Maitre (1965), gabbroic xenoliths (olivine-clinopyroxene-orthopyroxene-calcic plagioclase assemblages) occur abundantly in many of the basalt and trachybasalt flows, dykes and tuff horizons on Gough Island. He interpreted these xenoliths as fragments of upper mantle above the source area of the Gough magma. Finally, it must be noted that fractional crystallization models require what appear to be unduly large amounts of crystal extracts e.g. up to 40-43% of various combinations of olivine, clinopyroxene, kaersutite or spinel (*cf.* Brown and Carmichael, 1969; Gunn *et al.*, 1970).

In some studies it is assumed, more-or-less axiomatically, that a chemically and petrographically related series of alkaline lavas comprises a 'fractionated series' and a fractionation model is then tested by subtracting various phases, in the 'right' proportions, from a parent which is ideally assumed to be basaltic. The parent composition is most commonly adopted, partly because, I suspect, it has been more-or-less automatically assumed that *only* basaltic liquids are primary upper mantle derivatives. There is also a tendency to assume that ankaramites and oceanites, by virtue of prominent phenocrysts of clinopyroxene and olivine, represent the (low pressure) cumulates which are equated, at least in part, with the crystal extracts necessary to yield more evolved derivatives from some basaltic parent. This interpretation should be applied with caution. On the basis of 1-atmosphere melting studies Thompson and Flower (1971) have indicated that certain phenocryst-rich ankaramites (MgO 10-12%, CaO 10.1-12.3%) from Anjouan, Comores Archipelago, may have been formed by prolonged *in situ* crystallization of initially all-liquid magmas, with no appreciable relative movement of early-formed phenocrysts and liquids.

The genesis of alkali volcanic successions of extended composition, as commonly envisaged, thus evolves around a number of somewhat complicated, more-or-less 'ideal' processes. It commences with the partial fusion of (homogeneous) upper mantle peridotites and concomitant production of basaltic parents. If the most primitive partial melts are considered picritic (*cf.* Wilkinson, 1976) they are then required to shed olivine enroute to lower pressure regimes. The high-pressure extraction process whereby divorce occurs between partial melts and refractory residua must be extraordinarily efficient - at present there is apparently no evidence which demonstrates convincingly that a derivative partial melt has carried refractory residua of *its* parent to low-pressure regimes. The parent basalt melt than fractionates under relatively low-pressure conditions, crystallizing in the 'right' proportions phases which have differing crystal shapes, sizes and densities. The models often ignore phase relationships indicated by the experimentally determined crystallization behaviour of comparable melts, both at low and high pressures. The crystal extract is then largely or totally removed (with little or no evidence in the volcanic pile of its former presence) and so the production of the 'fractionated' series begins.

On the evidence of a chemical discontinuity near the basalt-"andesite" transition in many anorogenic volcanic suites, Thompson (1972a) has argued that "most tholeiitic andesites, hawaiites and trachyandesites" are generated at upper mantle depths as a result of high-pressure partial crystallization of bodies of basaltic magma. Release of evolved liquid residua only occurs when the masses are approximately half solid and the process is essentially one based on advanced fractionation. Alternative petrogenetic models for evolved alkaline volcanics, particularly those in the hawaiite-benmoreite spectrum, might also include: (i) partial fusion of relatively Fe-rich upper mantle lherzolites; and (ii) partial or (? complete) fusion of magmas already crystallized high in the upper mantle. Partial melting of a Snake River olivine tholeiite at 8 kb yields a tholeiitic andesite partial melt (Thompson, 1972b) and similar experimental data on alkali basaltic and related compositions are obviously desirable. At the same time, however, it must be commented that accidental high-pressure inclusions with compositions significantly more evolved than peridotitic (ultramafic) are apparently relatively rare in alkaline volcanics, if we are to judge from the data presently available on eastern Australian occurrences (Wass and Irving, 1976).

It has not been a purpose of this Lecture to discredit models based essentially on fractional crystallization processes. Rather it represents an attempt to direct attention to specific areas where detailed interpretative data are meagre but obviously required. More specifically, a number of major problems will undoubtedly be clarified by detailed studies of inclusion populations from alkaline hosts. The current situation on alkaline volcanic genesis has, I believe, been succintly summarized by Carmichael *et al.* (1975, p. 426): "The petrologist of today is much better equipped

than his predecessors to assess quantitatively the chemical trends of fractional crystallization. Quantitative models have been set up for a number of oceanic lava series - St Helena, Gough, Thingmuli in Iceland, some of the Hawaiian volcanoes, Tenerife in the Canaries. Models, however, they remain - and open to competition with yet other models that fit the growing data equally well or better. Many of the chemical data on which they are based can equally well fit more complex models in which the final stage is partial or complete fusion of previously consolidated (possibly already differentiated) magma. In view of this and of uncertainties regarding the site and pressure-temperature conditions of differentiation, no model can establish with certainty the actual course of differentiation. It serves rather to illustrate the kinds of events and processes that might have participated in some unique line of evolution whose varied products are tangibly represented as rocks of a unique volcanic series".

ACKNOWLEDGEMENTS

I thank L. Sutherland for generously providing unpublished analyses of Tasmanian lherzolite-bearing alkaline volcanics and H.D. Hensel for assistance with microprobe data. Research was supported by the University of New England.

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(Manuscript received 18.8.1977)

Journal and Proceedings, Royal Society of New South Wales, Vol. 110, pp. 139–145, 1977

Fossil Marsupials from the Douglas Cave, Near Stuart Town, New South Wales

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ABSTRACT. Marsupial remains from the Douglas Cave include *Thylacinus cynocephalus, Dasyurus viverrinus, Sminthopsis* sp., *Antechinus* sp., *Phascogale tapoatafa, Perameles nasuta, Isoodon obesulus, Cercartetus nanus, ?Acrobates* sp., *Lasiorhinus* sp., *Potorous tridactylus, Thylogale stigmatica, Wallabia bicolor, Macropus* sp., *M. agilia, M. giganteus, M. titan* and *M. altus*. A radiocarbon date of 29,200 years was obtained from near the base (Frank, 1969) of the older cave earth unit.

INTRODUCTION

Douglas Cave was discovered by 1896 by a Mr. R.J. Wilson (Leigh, 1897) in a limestone outcrop on Portion 93, Cooper Parish, in the County of Wellington about 8 km southwest of Stuart Town, central western N.S.W. (Figure 1). Leigh (1897) reported that a passage off the main chamber, the Bone Cave, was "literally packed with the fossilised bones of both herbivorous and carnivorous marsupials". A collection of bone was forwarded to the then Government Palaeontologist, W.S. Dun, who identified *Thylacinus spelaeus* Owen, *Dasyurus* sp., and *Macropus* sp. (Dun, 1897).

The next investigation was by Frank (1969), who mapped the cave, which he called the Douglas Cave, and described its clastic sediments and probable history. Animal remains were collected from pits dug by Frank into the two cave earth units in Douglas Cave, and were lodged at the Bureau of Mineral Resources, Canberra. The Initial description of this material was as part of the author's unpublished Honours thesis at the Australian National University.

CAVE STRATIGRAPHY

Frank (1969) recognised two cave earth units and sank a pit into each of these. Pit I in the older cave earth unit (Unit 1) reached a depth of 2.4 metres but was not excavated to bedrock. A radiocarbon date of 29 200 $\pm^{3000}_{2000}$ GaK - 1555 was obtained from charcoal near the base of the pit (Frank, 1969). Dates of 24 100 ±700 Gx - 1476 (Pit II) and 26 200 $\pm^{3300}_{2800}$ Gx 1477 (Pit I) were obtained from bone at the top of cave earth Unit I (Frank, 1972). As dates obtained from bones are probably underestimates, deposition of Unit 1 may have been rapid. A further date from bone near the base of Unit 1 in Pit I gave a date of 26 100 $\pm^{1600}_{1100}$ Gx - 1478 (Frank, 1972). Frank (1969) showed that Unit 1 was deposited through a solution pipe that opened some 30 000 years ago, and is probably about 2.5 metres thick. Bones* were collected down to 1.8 metres. After deposition of Unit 1 ceased, flowstone was deposited and forms the base of Unit 2. The second period of deposition was initiated by the opening of the present entrance as a collapse doline.

* in the Bureau of Mineral Resources possession

FAUNA

The distribution of the marsupial fauna from the two cave units is shown in Tables 1 and 2. Apart from marsupial remains, the cave earth units contain at least two species of lizard and several types of rodents which are at present undetermined.

PALAEONTOLOGY

Family	Macropodidae
Subfamily	Macropodinae
Genus	*Macropus* Shaw, 1790
	Macropus giganteus Shaw, 1790

Only one specimen from the Douglas Cave, DC4 from the top 15 cm of Pit I, is assigned to *Macropus giganteus*. The specimen, a right mandibular ramus, is of a juvenile with a partly shed DP_3, and erupted M_1, and a semi-erupted M_2 (Plate 2, figures 4, 5).

Comparison with measurements from Tedford (1967) and Bartholomai (1971) are shown in Table 4.

Genus	*Macropus* Shaw, 1790
	Macropus titan Owen, 1838

Two specimens (DC1 and DC8) are referred to the extinct giant kangaroo *Macropus titan*. Both occur in the 30-60 cm level of Pit I and represent two individuals. The specimens are both mandibular fragments containing molar teeth (Plate 1, figures 1,2,3), and compare closely with characteristics of *M. titan* as described by Bartholomai (1975). Measurements of the molar teeth are given in Table 3 together with measurements of *M. titan* given by Marshall (1974) and Tedford (1967). Length is plotted against posterior width in Figure 2 for the third lower molar of the Douglas Cave specimens, following the format of Marshall (1974). Both specimens lie towards the centre of the *Macropus titan* field and so are probably typical members of that species.

DISCUSSION

Lack of Larger Marsupial Remains

Comparison of the Douglas Cave fauna with other similar cave faunas indicates a lack of the larger marsupials: the diprotodontids and sthenurine kangaroos in particular. This omission

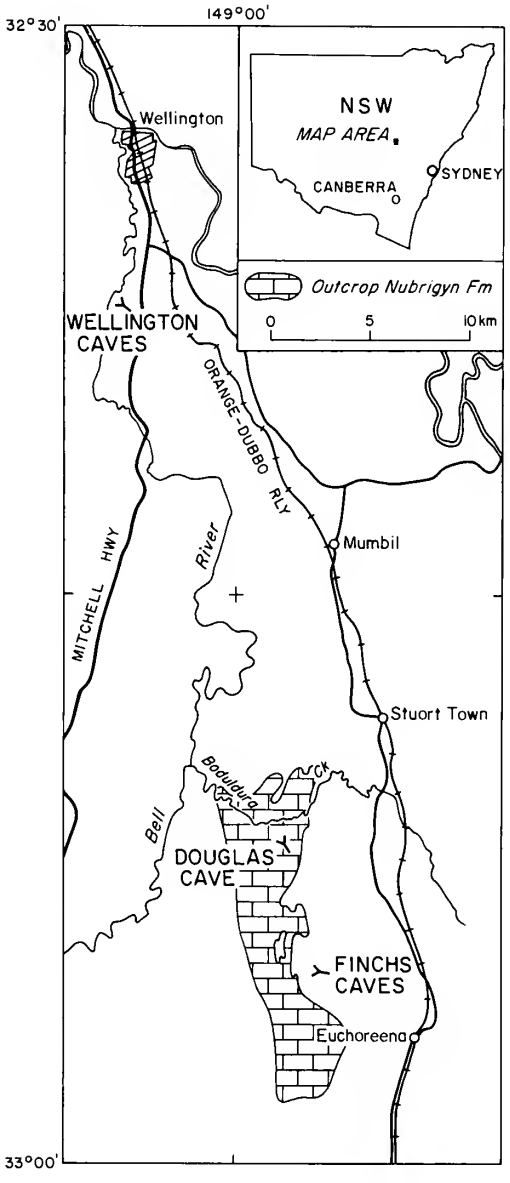

Figure 1. Locality map of the Douglas Cave.

from the fauna is surprising in view of the C^{14} dates (24 - 29 x 10^3 years B.P.), which place the older deposits well within the known stratigraphic range of the larger marsupials. The terrain around the cave is limstone karst, and such an environment may have proved unsuitable for animals as large as diprotodontids. As the cave opening is located high on a low rise with no higher ground in the vicinity, large remains would have been unlikely to have been washed in through the solution pipe described by Frank (1969), through which Unit 1 was deposited. From the fossil distribution (Table 1) it can be seen that no large marsupials are present in the Pit I deposit until the 60-120 cm level and that they become common only in the higher levels. This may reflect widening of the solution pipe, allowing larger macropods to fall in.

Large marsupials are similarly absent from the lowest level of Pit II but make their appearance at the 112 cm level. This may reflect the development of the collapse doline through which Unit 2 was deposited.

In conclusion, the absence of the larger marsupials from the deposit is thought to be caused by such factors as mode of deposition of the cave earth units and the geographical location of the cave, rather than extinction of larger marsupials before the case was opened.

On the Relationships between *Macropus titan* and *M. giganteus*

The only published occurrence of *Macropus titan* and *M. giganteus* in the same deposit is from Mammoth Cave, Western Australia (Tedford, 1967). However, Merrilees (1968) revised the Western Australian faunal list, and identified the Mammoth Cave *Macropus* as *M. fuliginosus*, not *M. giganteus*. Bartholomai (1975) further suggests that the occurrence of *M. titan* in Western Australia should also be checked. Thus the association of the two forms in Douglas Cave has relevance to the problem of the phylogenetic relationship of *M. titan* to *M. giganteus*. Tedford (1967) said that *M. giganteus* is "not readily derivable" from *M. titan*: whilst their molar characteristics are basically similar, those of *titan* are said to be slightly more complicated (Anderson, 1929). Marshall (1973) considers *M. titan* to be an example of Pleistocene gigantism, with *M. giganteus* as the surviving smaller form and recently Bartholomai (1975) concluded that separation of the two forms at the specific level is justified on size differential and various morphological grounds, and that "close relationship with the recent *M. giganteus* appears highly likely" (p. 205).

Marshall (1974) placed the date of transition between the two forms at about 20 000 years B.P. Discoveries of *M. titan* at Lancefield, Victoria, in swamp deposits dated as young as 12 000 years B.P. (D. Horton, personal communication 1976) put Marshall's estimate in question. However, Wright (1975) reports preliminary dates of about 12 500 B.P. on collagen and about 16 000 B.P. on apatite from bones recovered at Lancefield. Wright suggests these dates should be treated as minima because of the chemical environment of the swamp, and postulates that the bones are probably considerably older than 16 000 years. Flood (1974) referred macropodid material from Cloggs Cave, Victoria from deposits dated at 22 980 ±2 000 B.P. (ANU-1220), to *M. titan*. J. Hope (written communication, 1976) has re-examined this material and considers that the macropodid is referable to *M. giganteus*. Thus the oldest previously known *Macropus giganteus* is about 23 000 B.P., while the yougest *M. titan* is probably considered older than the nominal 16 000

TABLE 1

MINIMUM NUMBERS OF INDIVIDUALS FROM SAMPLED LEVELS IN CAVE EARTH UNIT 1, PIT I

Species	Bone Room Floor	Top 15 cm	30-60 cm	60-120 cm	120-180 cm
Thylacinus cynocephalus	1	-	-	-	-
Lasiorhinus sp.	-	1	-	-	-
Dasyurus viverrinus	-	-	-	-	1
Sminthopsis sp.	-	-	-	3	4
Antechinus sp.	-	-	-	4	7
Phascogale tapoatafa	-	-	-	1	-
Cercartetus nanus	-	-	-	3	1
?Acrobates sp.	-	-	-	1	1
Perameles nasuta	-	-	-	4	5
Isoodon obesulus	-	-	-	2	5
Potorous tridactylus	-	-	-	1	-
Thylogale stigmatica	-	1	-	-	-
Wallabia bicolor	-	1	-	-	-
Macropus sp.	Present	Present	Present	Present	-
M. agilis	-	1	-	-	-
M. giganteus	-	1	-	-	-
M. titan	-	-	2	-	-
M. altus	-	4	1	1	?

TABLE 2

MINIMUM NUMBERS OF INDIVIDUALS FROM SAMPLED LEVELS IN CAVE EARTH UNIT 2, PIT II

Species	Top 30 cm	70 cm	112 cm	120 cm	Bottom 30 cm
Sminthopsis sp.	2	-	-	-	-
Antechinus sp.	1	-	-	-	2
Dasyurus viverrinus	1	1	-	-	-
Perameles nasuta	1	-	-	-	1
Isoodon obesulus	-	-	-	-	1
Cercartetus nanus	1	-	-	-	-
Macropus altus	-	1	2	-	-

TABLE 3

DIMENSIONS OF LOWER TEETH OF *MACROPUS TITAN* (DC 1, DC 8) IN MILLIMETRES.

L = Length, AW = Anterior width, PW = Posterior width, measured across the lophids.

Specimen		P_3	M_1	M_2	M_3	M_4
DC 1	L	-	-	ca 16	17.1	19
	AW	-	-	9.6	10.6	10.6
	PW	-	-	10.4	10.5	10.4
DC 8	L	7.9	-	14	16.5	-
	AW	-	-	10.2	10.5	-
	PW	-	9.25	10	10	-
Marshall (1974)	L	-	13-14	13.8-16	15.5-17.4	17-19
	AW	-	7.7-8	8-9.7	9.5-11.6	9.9-11.6
	PW	-	8.2-8.7	9.5-10.4	9.2-11	9.3-11.2
Tedford (1967) *titan*	L	-	-	-	15.5-19	16.1-20.2
	AW	-	-	-	9.2-11.2	9.4-11.6
	PW	-	-	8.5-10.5	-	8.9-11.2

TABLE 4

DIMENSIONS OF LOWER CHEEK TEETH OF SPECIMENS ASSIGNED TO *MACROPUS GIGANTEUS* IN MILLIMETRES

Specimen		DP_3	M_1	M_2	M_3	M_4
DC 4	L	8.2	10.7	12-13	-	-
	AW	5.6	6.6	7.0	-	-
	PW	6.0	6.8	-	-	-
Range for lower molars, from Bartholomai (1971)	L	-	8.6-11.7	8.9-13.2	11.4-14.3	11.8-14.9
	AW	-	4.7-6.8	5.7-7.9	6.6- 8.5	6.7- 8.7
	PW	-	-	-	-	-
Range for lower molars, from Tedford (1967)	L	-		-	11.4-14.4	12.5-15
	AW	-		-	6.7- 8.8	8 - 8.9
	PW	-	-	6.3-8.5	-	7.1- 8.5

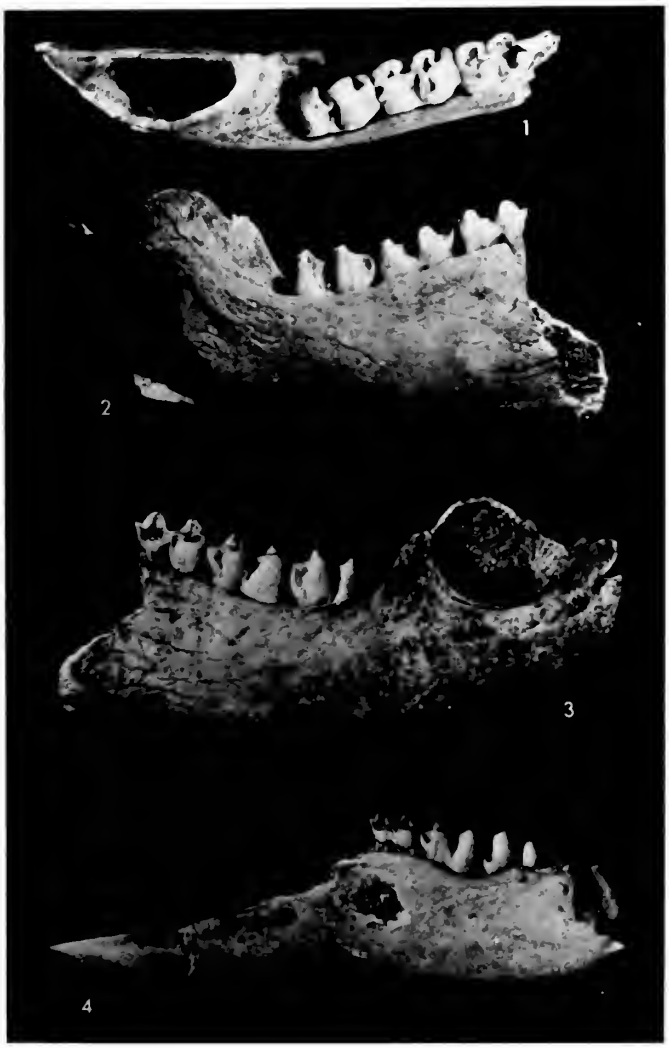

Plate 1. All illustrations are two-thirds natural size.

Figure 1. *Macropus titan* from 30-60 cm level of Pit I, Douglas Cave. Occlusal view of broken left mandible DC 1 (CPC 17108).

Figure 2. Lingual view of same.

Figure 3. Labial view of same.

Figure 4. *Macropus altus* from 30-60 cm level of Pit I, Douglas Cave. Labial view of broken left mandible DC 9 (CPC 17109).

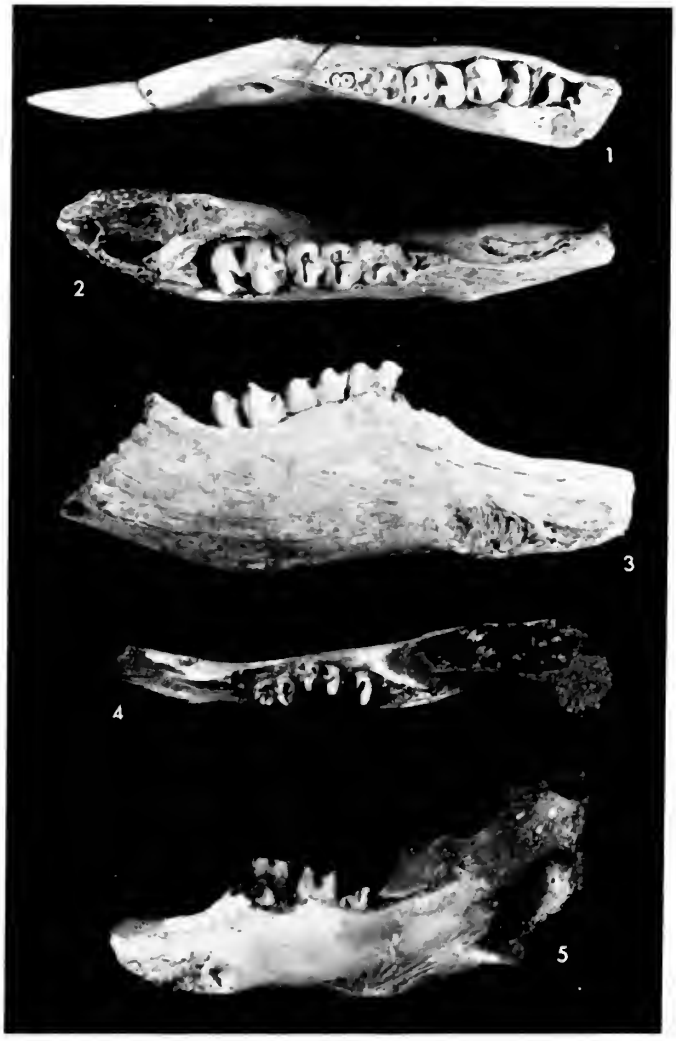

Plate 2. All illustrations are two-thirds natural size.

Figure 1. *Macropus altus* from 30-60 cm level of Pit I, Douglas Cave. Occlusal view of broken left mandible DC 9 (CPC 17109).

Figure 2. *Macropus altus* from 30-60 cm level of Pit 1, Douglas Cave. Occlusal view of broken left mandible DC11 (CPC 17110).

Figure 3. Lingual view of same.

Figure 4. *Macropus giganteus* from top 15 cm of Pit I, Douglas Cave. Occlusal view of broken right mandible DC 4 (CPC 17111).

Figure 5. Labial view of same.

B.P. date from Lancefield.

In view of the close stratigraphic relation of the two species in the Douglas Cave, it is probable that there was a period of co-existence of the older *M. titan* with the more recent *M. giganteus*.

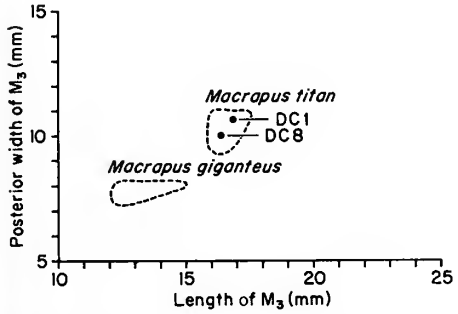

Figure 2. Scatter diagram of LM_3 against PWM_3 of *Macropus titan* from the Douglas Cave, compared with the fields for *M. titan* and *M. giganteus* as presented by Marshall (1974).

ACKNOWLEDGEMENTS

Dr. Jeanette Hope of the Australian National University read the first draft of this paper and made many helpful suggestions. The figures were drawn by M. Moffatt.

Comparison with material in the possession of J. Hope, C.R. Tidemann, J.H. Calaby, and D. Horton was made in the course of this study. I would like to express my thanks to M.D. Plane, my supervisor during this study while the writer was at the Australian National University. This article is published with permission of the Director, Bureau of Mineral Resources.

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(Manuscript received 1.1.77).

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